Petroleum Experts

User Manual

IPM

MBAL

Version 10.5

July 2012

MBAL

IPM - Analytical Reservoir Model OVERVIEW

by Petroleum Experts Limited

The MBAL package contains the classical reservoir engineering tool, which is part of the Integrated Production Modelling Toolkit (IPM) of Petroleum Experts.

MBAL has redefined the use of Material Balance in modern reservoir engineering. MBAL has many innovations developed by Petroleum Experts that are not available elsewhere.

MBAL is the industry standard for accurate Material Balance modelling. Efficient reservoir developments require a good understanding of reservoir and production systems. MBAL helps the engineer define reservoir drive mechanisms and hydrocarbon volumes more easily. This is a prerequisite for reliable simulation studies.

For existing reservoirs, MBAL provides extensive matching facilities. Realistic production profiles can be run for reservoirs, with or without history matching. The intuitive program structure enables the reservoir engineer to achieve reliable results quickly. MBAL is commonly used for modelling the dynamic reservoir effects prior to building a numerical simulator model.

APPLICATIONS

- *History matching reservoir performance to identify hydrocarbons in place and aquifer drive mechanisms*
- *Building Multi-Tank reservoir model*
- *Generate production profiles*
- *Run development studies*
- *Determine gas contract DCQ’s*
- *Model performance of retrograde condensate reservoirs for depletion and re-cycling*
- *Decline curve analysis*
- *Monte Carlo simulations*
- *1D flood front modelling*
- *Calibrate relative permeability curves against field performance data*
- *Control Miscibility*
- *Control recycling of injection gas*
- *Fully Compositional*
- *MBAL’s logical and progressive path leads the engineer through history matching a reservoir and generating production profiles. The program is easy to use and fast to learn*
- *MBAL allows the engineer to tune PVT correlations to match with field data. This prevents data errors being compounded between modelling steps*
- *MBAL’s menu system minimises data entry by selecting only data relevant to the calculation options selected*

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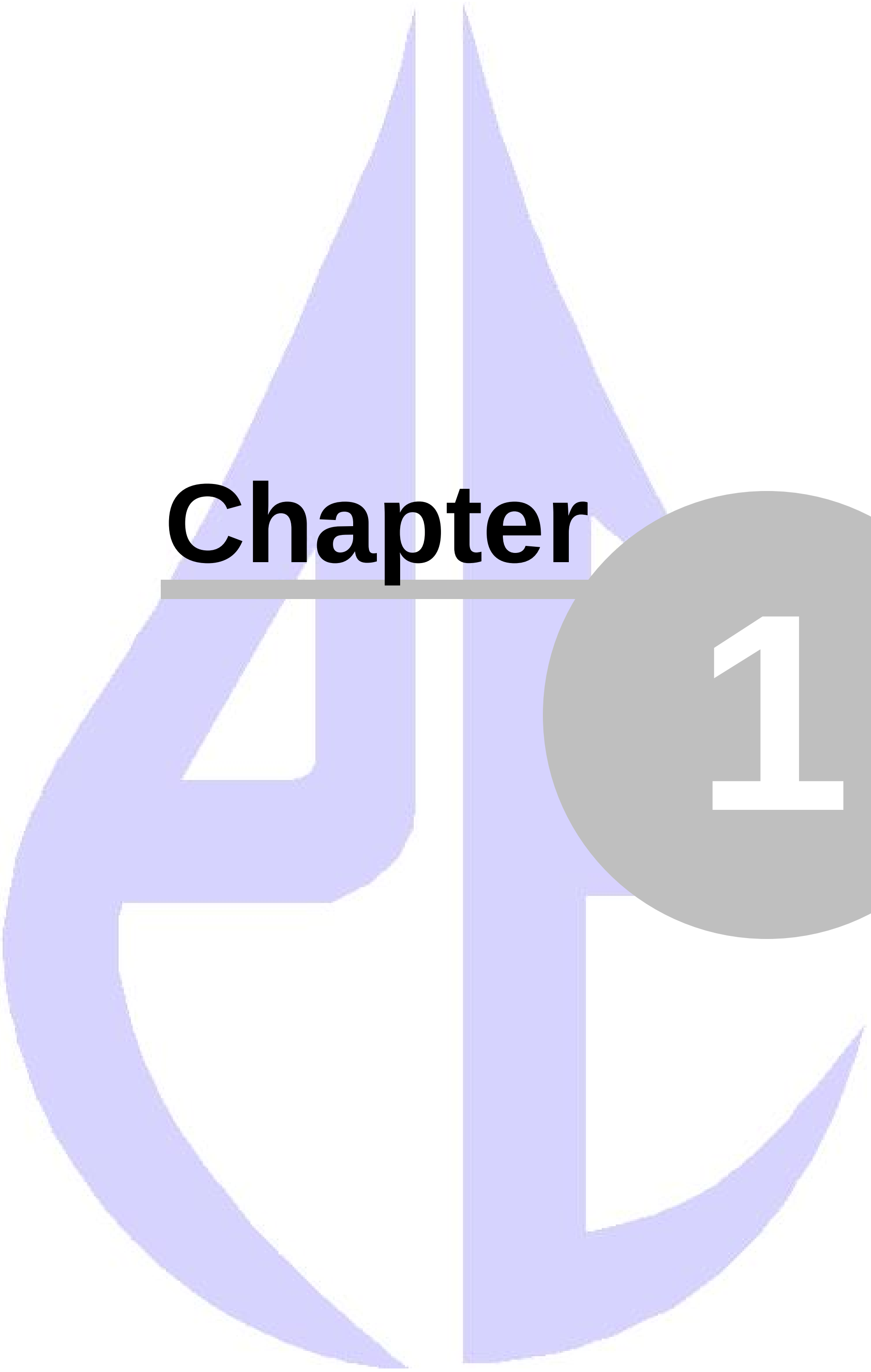


Chapter

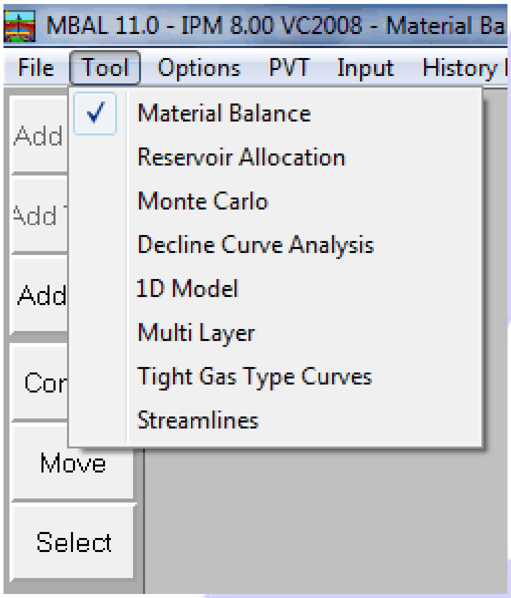
1

1 Technical Overview

PETROLEUM EXPERTS **MBAL** is a reservoir modelling tool belonging to the **IPM** suite.

This tool was designed to allow for greater understanding of the current reservoir behaviour and perform predictions while determining its depletion.

Reservoir modelling can be carried out within **MBAL** with the use of several different tools to focus on different aspects: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Monte Carlo
Decline Curve Analysis
1D Model
Multi Layer
Tight Gas Type Curves
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- **Material Balance,**
- **Reservoir Allocation**
- **Monte Carlo volumetrics,**
- **Decline Curve Analysis,**
- **1-D Model (Buckley-Leverett) and 1-D model with EOR**
- **Multi-Layer (relative permeability averaging)**
- **Tight Gas Type Curve tool**
- **Streamlines**

Each of the available tools and the methods available for the fluid behaviour modelling are defined below.

1.1 Material Balance

The material balance concept is based on the principle of the conservation of mass:

Mass of fluids originally in place = Fluids produced + Remaining fluids in place.

This can be synthesised in the fundamental equation:

$$F = N \cdot E_t + W_e$$

where:

F is the production

E_t is the expansion term, depending on PVT and reservoir parameters

W_e is the water influx term

The material balance program uses a conceptual model of the reservoir to predict the reservoir behaviour based on the effects of reservoir fluids production and gas to water injection.

The material balance equation is zero-dimensional, meaning that it is based on a tank model and does not take into account the: geometry of the reservoir, the drainage areas, the position and orientation of the wells, etc.

However, the material balance approach can be a very useful tool in performing many tasks, some of which are highlighted below:

- Quantify different parameters of a reservoir such as hydrocarbon in place, gas cap size, etc.
- Determine the presence, the type and size of an aquifer, encroachment angle, etc.
- Estimate the depth of the gas/oil, water/oil, gas/water contacts.
- Predict the reservoir pressure for a given production and/or injection schedule,
- Predict the reservoir performance and manifold back pressures for a given production schedule.
- Predict the reservoir performance and well production for a given manifold pressure schedule.

Fluid PVT Modeling

MBAL allows to model any type of reservoir fluids: Oil, Dry and Wet gas, Retrograde Condensate. A 'General' type of fluid allows the user to define independent PVT models for the oil and the gas in equilibrium, in this way, modelling the gas bubbling out of the oil and condensate dropping out of the gas.

The fluid behaviour when material balance is in use can be modelled with the use of three available methods:

Black Oil Correlations	The parameters used within material balance to define the fluid and phase behavior (Bo, Bg, GOR etc.) are calculated and entered into material balance
Equation of State	The use of an equation of state to define the phase and composition of the fluid across the entire system
Tracking	In essence, this is a combination of Black Oil correlations and EOS. The black oil correlations are used to model the pressure drop calculations across the system and equation of state is then applied to determine the composition at given points in the system by performing compositional blends and flashes. This is a unique capability possessed by **MBAL** which ensures that the produced fluid GOR can be recombined to match to the initial fluid composition

Greater detail for each method and its applicability for different fluids (oil, gas or retrograde condensate) are defined under Describing the PVT 70.

High Relief Reservoirs

The fluid PVT can be considered homogenous within the reservoir, or variable with depth. This allows to model PVT properties varying with depth within high relief reservoirs.

Multiple Tanks

The reservoir structure can be modelled with a unique tank or with multiple tanks connected by means of transmissibilities. This option is useful in cases of complex reservoir geology that cannot be simplified to a simple homogenous tank.

History Matching

MBAL is renowned in the industry as the state of the art material balance modelling and history matching tool. Several history matching methods can be used to match, cross check and quality check the model against past production history.

The main methods available are shown below. Each method may have sub-methods that will be described in further chapters:

Graphical method	This consists of rearranging the material balance equation in opportune ways in order to achieve plots with special properties
Analytical method	This consists of calculating the main phase production (for example, oil) on the basis of the historical reservoir pressure variation and history of production of the secondary phases (for example gas, water), and then comparing the model results with the production history of pressure and main phase production
Energy Plot	This consists of a qualitative plot that is able to quickly identify the main drive mechanisms in the reservoir
Wd function plot	This consists of a dimensionless plot of water influx vs time describing the aquifer response over time

Production history data can be defined for the total reservoir or for each well producing.

Coalbed methane (NEW!!!)

IPM 7.5 is released with a major development in MBAL: Coalbed Methane. Two options are available to model coalbed methane in **MBAL**: using the classical material balance tool or inside the tight gas type curves tool when the production is expected to show significant transience.

1.2 Reservoir Allocation

When a well has been producing from multiple layers, it is essential for an engineer to know how much each layer has contributed to the total production to understand how best to manage the well and field production. Traditionally, this reservoir allocation has been done based on the kh of each layer.
This approach does not take the IPR of the layers into account and also ignores the rate of depletion of the layers.
The 'Reservoir Allocation' tool in **MBAL** improves the allocation by allowing the user to enter IPRs for each layer and calculates the allocation by taking the rate of depletion into account as well. Crossflow is also accounted for in the model, as well as different start and finish times for the wells. Impurities are also tracked and can provide an effective measure of the quality of the underlying assumptions in the case where little data is available.

This system can be used to define the historical production from each layer for oil, gas or retrograde condensate.

1.3 Monte Carlo

The Monte-Carlo technique is used to evaluate the hydrocarbons in place. Each of the parameters involved in the calculation of reserves; basically the PVT properties and the pore volume are represented by statistical distributions.

Depending on the number of cases (NC) chosen by the user, the program generates a series of NC values of equal probability for each of the parameters used in the hydrocarbons in place calculation. The NC values of each parameter are then cross-multiplied creating a distribution of values for the hydrocarbons in place. The results are presented in the form of a histogram.

We link the probability of Swc and porosity to reflect physical reality. If the porosity is near the bottom of the probability range, the Swc will be weighted to be more likely to be near the bottom of the range. Similarly if the porosity is near the top of the range, the Swc will be weighted to be near the top of the range. The same method is used to link the GOR and oil gravity.

Oil, gas or retrograde condensates can be modelled within this system.

1.4 Decline Curve Analysis

This tool analyses the decline of production of a well or reservoir versus time. It uses the hyperbolic decline curves described by Fetkovich based on the equation:

$$\frac{q}{q_i} = \left(1 + bi * a * \Delta t\right)^{-\frac{1}{a}}$$

where:

q	is the production rate,
qi	is the initial production rate,
a	is the hyperbolic decline exponent,
bi	is the initial decline rate,
t	is the time.

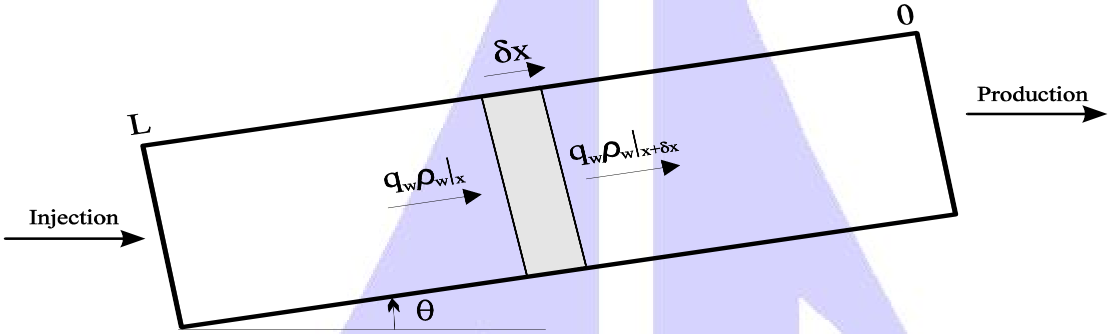
Curves can be matched to reproduce past history of production, or entered directly in the model.

The program also supports production rate 'breaks' or discontinuities. These breaks can be attributed to well stimulation, change of completion, etc.

Oil, gas or retrograde condensates can be modelled while using this method.

1.5 1D Model

This tool allows the study of the displacement of oil by water or gas, using the fractional flow and Buckley-Leverett equations. The model does not presuppose any displacement theory.



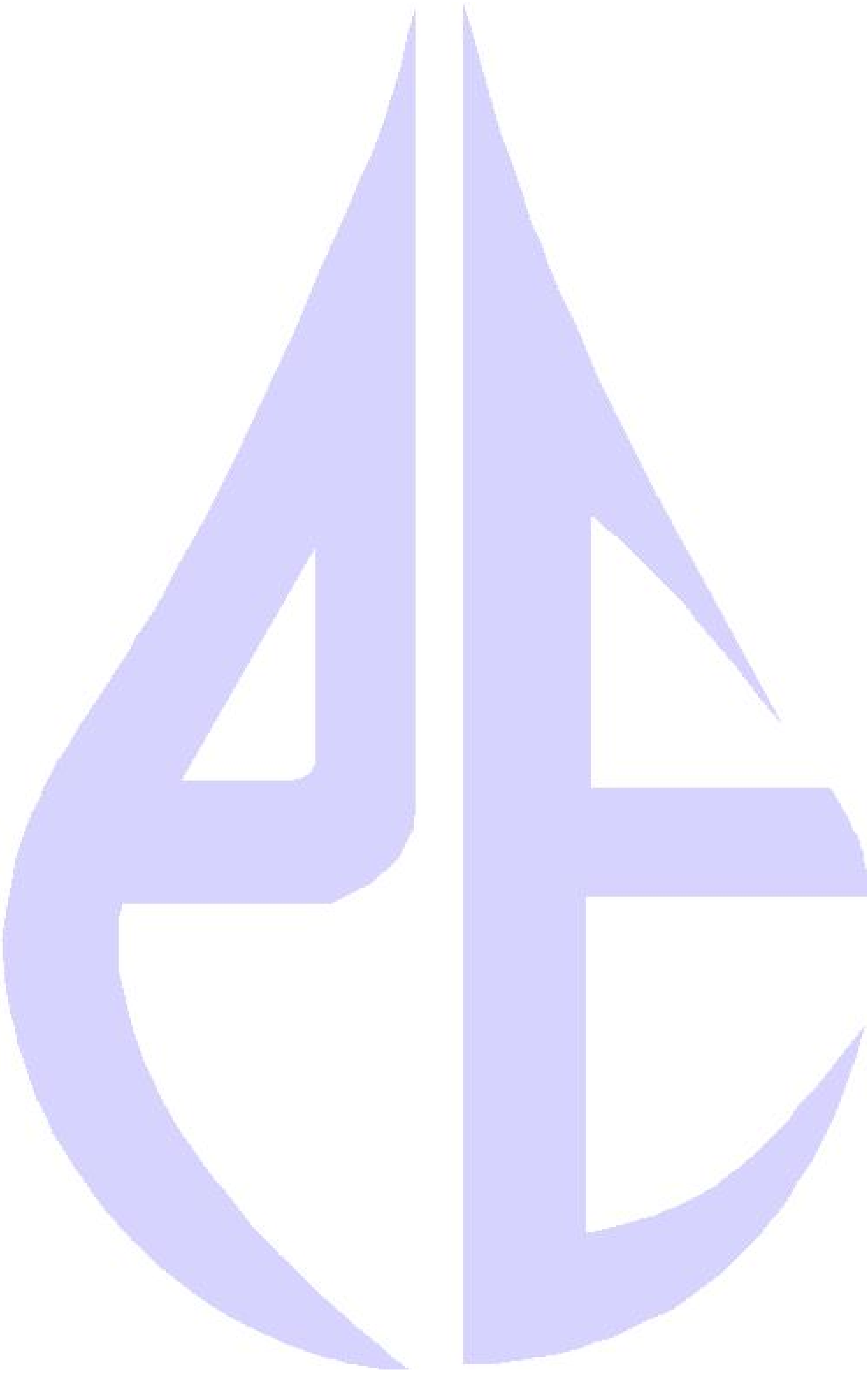
The model assumes the following:

- The reservoir is a rectangular box with an injector well at one end and a producer at the other.
- The production and injection wells are considered to be perforated across the entire formation thickness.
- The injection rate is constant.
- The fluids are immiscible.
- The displacement is considered as incompressible.
- The saturation distribution is uniform across the width of the reservoir.
- Linear flow lines are assumed, even in the vicinity of the wells.
- Capillary pressures are neglected.

As this method is used to model the displacement of oil, this is the only fluid which can be modelled using this tool.

New in IPM8.0

The 1D model has also been extended for simple analytical EOR type studies such as CO2 injection, surfactant and polymer flooding, hot water injection e.t.c.



1.6 Multilayer

The purpose of this tool is to generate pseudo relative permeability curves for multi-layer reservoirs using immiscible displacement. These can then be used by other tools in **MBAL** such as Material Balance.

A single PVT description can be entered. A single pressure and temperature is entered for the reservoir which is used to calculate the required fluid properties.

Each layer has its own set of relative permeabilities, thickness, porosity and permeability.

The model considers the incline of the reservoir in all calculation types apart from Stiles method.

The steps include:

- Specify the injection phase (gas or water)
- Specify the calculation type; Buckley-Leverett, Stiles, Communicating Layers or Simple.
- Enter the PVT description.
- Enter reservoir description
- Enter the layer description
- Calculate the production profile for each layer and combine all the layers into a consolidated production profile. Since we are only interested in the relative layer response, we use a dimensionless model wherever possible (e.g. length=1 foot and injection rate =1 cf/d).
- Calculate a pseudo relative permeability curve for the reservoir using the Fw/Fg match plot.

If required the pseudo-layer calculated from the multi-layers created by the above steps can then be reused as a single layer in a new model. For example a pseudo-layer calculated from a communicating multi-layer model can be used as input for a single layer Buckley-Leverett model. Or one could even run two different multi-layer communicating models and use the two pseudo-layers as input to a multi-layer Buckley-Leverett model.

Either oil or gas can be modelled within this system, while water or gas can also be used as the injection fluid.

1.7 Tight Gas Type Curves

A tight gas reservoir is thus described due to the low permeability that is prevalent. The low permeability results in long periods of transient flow for which the material balance theory is not applicable. Therefore this model was developed in response to the industry requirement to calculate (i) the GIIP and (ii) perform forecasting calculations in transient gas reservoirs without resorting to numerical simulation.

Material balance is only valid when the reservoir has developed fully into pseudo-steady state, which is when average reservoir pressures can be estimated.Using MBAL in the transient period will lead to errors in the estimation of the gas in place and forecasted volumes.

The transient period for a tight gas system can actually be quite long, and in such cases, this tool can provide an alternative for history matching and forecasting. It is based on well testing theory and incorporates a number of plots that can assist with history matching these type of reservoirs.

As implied by the title, this model focuses on gas alone to analyse the bottom hole pressure data from individual wells. Further detail and examples of the uses for the above models is available throughout this document.

This document explains the basic procedures to follow in order to set-up a **MBAL** model using the examples provided. This user guide focuses on how to use the various program features as analytical tools to solve engineering problems. The section titled 'Example Guide' contains worked examples and the appendix gives a list of the references for the various models implemented in the **MBAL** software package. Users of this software will be able to find even greater detail if referring to the references defined in the Appendix.

1.8 Streamlines

Streamline module in MBAL provides a quick 2-D reservoir simulator to estimate:-

- Sweep Efficiencies
- Producer well fractional flows

for a set pattern of water injectors and oil producers.

This does not replace a reservoir simulator but does allow quick analysis of different well patterns and their effect on the recovery.

The tool currently models a rectangular reservoir with a combination of no-flow or constant pressure (aquifer) boundaries.

1.9 What's New

Version 11

MBAL Version 11 - Enhancements Implemented:

Coal Bed Methane

- New IPR calculation method added which calculates three fluid phases directly from the relative permeability information. This is unlike standard IPR methods where the major phase is calculated and then others are obtained from the WGR or CGR etc.
- Modification to the pseudo relative permeability curves to allow the option for Krw decrease once Sg>0 or Krw decrease when Sg > Sgr.
- LIft curves now include water liquid level as part of information for modelling. LIquid level can be entered for CBM wells.

Tight Gas Model

- Improvements in pseudo-time calculations to better account for fluid properties changes with pressure.
- Now possible to enter WHP instead of BHP as historical data. The BHP will be calculated from the WHP using a lift curve.
- Inclusion of Wattenbarger plot.

1 D Model with EOR

- Extension of 1D Model for EOR studies: Polymer, surfactant and CO2 flooding.

Streamlines

- Streamlines added as a new tool/feature in MBAL. Userful for estimation of sweep efficiencies and well fractional flows.

Version 10.5

MBAL Version 10.5 - Enhancements Implemented:

Coal Bed Methane

- Option added to material balance tanks and tight gas wells to allow modelling of coabed methane reservoirs using Langmuir isotherms to determine how much gas is desorbed from the rock surface and released into pore space

Tight Gas Model

- Constrain cumulative gas production to OGIP in tight gas models

OpenServer

- Evaluate OpenServer dialogue added to 'File' menu

PVT Modelling

- Added Bergman-Sutton correlation for oil viscosity

Version 10.0

MBAL Version 10.0 - Enhancements Implemented:

Tight Gas Model

- Agarwal-Gardner Type-curve matching for tight gas tool
- Also implemented for tight gas tool to allow modelling of WGR

Fractional Flow

- Look-up table for fractional flow instead of relative permeability curves
- Control of regression variables for fractional flow matching

Compositional Lumping/Delumping

Production History

- Import multiple well production history
- Entry of production history by month or year
- Undo facility in history matching
- Plotting of prediction well rates against history well rates

PVT

- New Al-Marhoun PVT correlation for Pb, Rs & Bo

Miscellaneous

- Handle gas-lift curves with casing head pressure
- Ability to change units in dialog
- Allow edit/view of well relative permeability (prior to import to GAP)
- Plot IPR with and without gravel pack

Version 9.0

MBAL Version 9.0 - Enhancements Implemented:

New Tight Gas Tool

- Allows analysis of transient reservoirs for gas only.

Material Balance Tool

- Correct IPR for the effect of gravel pack
- Prediction based on 'Production Schedule' for multi-tanks.
- Extend prediction type 1 (from production schedule) to multi-tank cases
- Prediction to 'Calculate Minimum Number of Wells' to achieve target rate.
- Improvements to 'Production History' input

- Enter comment for each history point and display on plots
- Display weighting in production history dialogue

Improvements on Graphical Plot

- Campbell & Cole plot without aquifer
- Best line fit over selected range of points
- Option to try various line fits before committing to tank data.
- Check valve on transmissibilities
- Calculate the GOR etc. in history simulation from rel perms and saturations
- 'Accept All Fits' button on analytic plot regression.

Version 8.0

MBAL Version 8.0 - Enhancements Implemented:

Production Allocation Tool

Impurity Tracking

- Track CO2, N2 and H2S to allow comparison with measured values.

Allow transmissibilities

- Model transmissibilities to connect tanks.

Material Balance Tool

- Full compositional model
- Completely new model to perform molar balance in tanks instead of material balance
- Uses fluid properties calculated from compositional models for IPR and VLP well calculations

New Contact Calculation

- New method added for oil tanks to model residual gas saturation trapped in the oil zone.

Rock Compaction Model

- New model to allow comparison with reservoir simulators.

New *OpenServer* Commands

- Perform allocation of well production.
- Run regression calculations in history matching.
- New commands to allow models to be created from scratch.

- Import PVT file into PVT dataset

New water producer well types (including ESP, HSP and PCP)

- Allow oil and gas wells to produce from water tanks
- Downhole pore volume reported in the simulation/prediction
- Simulation/Prediction plots have option to plot all streams in different colours

All Tools

Plotting improvements

- Number of grid blocks is now configurable.
- Scales can be saved on several plot types.

Table Input Grids

- Cut/Copy/Paste/Clear available for selected rows and columns.

Minimum calculation unit reduced to 1 second

- Previously the smallest time unit was one day
- Calculations can now be performed down to one second
- To do this, the data unit in the units system needs to be altered to something other than calendar date setting e.g hours, seconds or date/time

Version 7.0

MBAL Version 7.0 - Enhancements Implemented:

Production Allocation Tool

- New tool to calculate layer rates when only total well rates are available.

Material Balance

Water vapour correction for gas

- Option to model the water vapour in the gas. Can be used in gas, condensate and general fluid options.

Water Coning

- Option to model water coning in oil tanks.

Gas injection gravity modelled in history matching

- Gas injection gravity can now be entered in the tank history. It is then taken into account in the history matching
  options

Two-phase Relative Permeability Plots

- Option to plot relative permeability curves in traditional two-phase layout.

Relative Permeability Inflow Correction for Gas

- Add ability to correct the inflow performance for changes in relative permeability for gas and condensate wells.

    - Abnormally Pressured Reservoir Method **-** A new method for analysing gas reservoirs.

Maximum DCQ constraint

- A constraint has been added to allow a maximum DCQ to be set when using the prediction type that calculates a DCQ.

Relative Permeability Hysteresis

- An option is now available to model hysteresis for relative permeability curves.

New contact calculation method to include trapped saturations

- New method for calculating fluid contact calculations that include trapped phases.
- Results column layouts are retained after new calculations.

New option to calculate system rate constraints on instantaneous rates

- In previous versions MBal always calculated the system constraints on average rates.
- Definition of Pore Volume vs Depth table has been changed. For oil tanks, top of gas cap is now always PV = -1. For condensate tanks, bottom of oil leg is now PV = 2. See Pore volume vs Depth for more information.

- **Option to display file name in hard copy of plots**

Generalised Material Balance

- Gas injected into tanks can now flow through transmissibilities into other tanks
- Separate manifolds are now available for producers from the oil leg and gas cap. Rates are reported for each manifold as well as the total production rates
- Constraints can be applied to each manifold. Alternatively the oil leg and gas cap producers can share a common manifold
- Impurities and compositions (both originally in the tank and injected) are now tracked through transmissibilities and crossflow
- Added Fayers and Mathews method to calculate combined Sor for Stones 1 Relative Permeability model
- Pb calculation available on tank parameters tab
- Copy PVT tables to match data or match data to tables. Also copy from one PVT object to another
- Added gas-oil contact depth as a layer abandonment for gas coning
- In the 'Reporting Schedule', any number of dates can be entered in the 'User Date' list

Version 6.5

MBAL Version 6.5 - Enhancements Implemented:

Improved Multi-layer Tool

- Improved multi-layer tool to perform Stiles, Buckley-Leverett and Communicating layers models.

Material Balance

- Populate rel perm tables from Corey table
- New option to calculate relative permeability tables from Corey exponents

Reference time

- All times can be displayed in days, weeks, months or years from a reference date

Cf defined as tangent

- The rock compressibility referenced back to initial pressure can be calculated from the rock compressibility entered as a tangent

Separate rel perms for mobility correction

- A separate set of relative permeability tables can be entered and used only for the various mobility corrections for the PI

Breakthroughs per tank

- For prediction type 1 (pressure from production schedule), phase breakthroughs can now be entered

Allow single tank name to be edited.

All Tools

Plotting improvements

- These include configurable fonts on screen, new defaults colours with white background, different colour scheme for screen and hard copy

Version 6.0

MBAL Version 6.0 - Enhancements Implemented:

Material Balance

Generalised Material Balance

- New option to model a tank containing either initial oil, condensate or both. Also allows control of re-production of injected gas

Controlled miscibility

- New option in the PVT section to allow re-dissolving of gas back into the oil to be controlled

PVT per Tank

- New option to allow a different PVT dataset to be assigned to different tanks. Note that when fluid moves from one tank to another the fluid is considered to have 'changed' into the fluid in the target tank

Append File
- Option to read tanks, wells etc from a file and append them to **MBAL** without destroying the current data

Enhanced Open Server
- Predictions can now be run step by step. Selected input data can be changed during the prediction such as manifold pressure, PI etc

Variable PVT Datum
- A datum other than the initial GOC can be entered for the variable PVT option

Variable PVT with Multi-tank
- The variable PVT option can now be used with the multi-tank option. Different variable PVT inputs can be used for different tanks

Calculate Rate Only
- Option to calculate rate only in consolidation of production history from different wells

Correct Vogel
- IPR rel perm correction option which includes the reduction of the Kro and Krw due to the gas saturation

Plot Line Widths
- Allow line widths to be set on plots

Export PVT Files
- The PVT data can be exported to a PVT file that can be read by **PROSPER**

Removed Prediction Type 2
- Calculation of manifold pressure from production schedule
- Added option to history setup to use transmissibility rates in the graphical plots.

All Tools
- Conversion to 32 bit

Version 5.0

MBAL Version 5.0 - Enhancements Implemented:

Material Balance
Compositional Tracking
- **MBAL** can now track a composition through a simulation or prediction

Oil breakthroughs

- Oil breakthroughs are now available for condensate wells

Relative Permeability Curves for Transmissibilities

- Relative permeability curves can now be assigned to a transmissibility. These curves can be matched in Fw/Fg/Fo matching

Pressure dependant permeabilities

- Changes in the tank permeability can now handled in IPR calculations and transmissibility

Improved transmissibility matching

Gas Coning

- Gas coning can be modelled for oil tanks. This uses a gas coning model to calculate the GOR for each layer rather than using the relative permeability curves

Injectivity Index for Crossflowing Production Wells

- For multi-layer wells, an injectivity index can be entered for production wells to allow control of crossflow

Linked Voidage Replacement to Injection Wells 281

Multi-layer

- This is a new tool to allow calculation of a set of pseudo-relative permeability curves for a tank which is made up of a number of layers which are each described by their own relative permeability curve

All tools

Open Server

- Access Mbal variables and functions from external programs via automation or batch file.

Major bug fixes

- Fixed calculation error in the gas transmissibility rate for the condensate option
- Fixed error in the well Fw/Fg/Fo matching - it was using rate data which was two time steps behind the saturations and fluid properties
- The saturations used to be limited to between 0 and 1 in the prediction/history simulation results. This limit has been removed to assist in diagnostics. Note that it was only a reporting change - there is no change to any other results. This means that in situations where we get negative gas/water/oil in place warnings and the user chooses to proceed, negative gas/water/oil saturations will be reported.
- Instantaneous transmissibility rates have been replaced by the average rates - this is because the rates are always calculated over a step and instantaneous rates have no meaning
- Maximum FBHP constraints has been removed for producer wells. Minimum FBHP has been removed for injector wells. This is because there is no physically realistic method for imposing these constraints.

- In production allocation from history wells, it used to simply calculate the tank cumulative rate from the allocation multiplied by the cumulative rate of each well. It has been changed so that it now multiplies the delta rate on each calculation step in the allocation. Note that this change makes no difference unless:
  - the allocation factor is changed over time in at least one of the production wells
  - the cumulative well rate is zero at the start time
  - Also fixed a bug in production allocation for multi-tank cases
  - Changed calculations in the gas storage. In V4.1, it tracked the volume that the injection gas filled in the tank (the gas zone). It never allowed the size of the gas zone to shrink during a production cycle. It would allow the size to increase if a subsequent injection cycle increased the size above the last maximum. During the production cycles, it used the saturations of the gas and water in the gas zone to calculate the relative permeabilities. This was to allow gas to be produced even if there was only a small amount at the very top of the tank
  - It was felt that since the size of the gas zone was constantly changing, it was better to use the total saturations of the tank and use a large water breakthrough for the well (plus relative permeability correction). Note that this means that the prediction type one (calculating pressure from a production schedule) can not easily be used for gas storage as there is no way to enter breakthroughs
- Variable PVT was not taking production of history wells into account in History Simulation. Also was not taking depleting correct layer in production prediction
- Instability in Hurst-van Everdingen-Modified Linear aquifer model with Sealed boundary was fixed.

Version 4.1 - Release 1

MBAL Version 4.1 - Enhancements Implemented:

Material Balance

Transmissibility Threshold

- **MBAL** can now model a threshold pressure on transmissibilities

Production Analyst Import

- A set of wells or tanks can be imported from a PA file in a single operation

Relative Permeabilities per Layer

- A set of relative permeabilities may be entered per layer (i.e. tank/well interface)

Version 4.0 - Release 1

MBAL Version 4.0 - Enhancements Implemented:

Material Balance

Multiple Tanks

- **MBAL** can now handle multiple tanks with transmissibility objects defining how fluid flows between them. It also allows matching of transmissibility

Variable PVT

- **MBAL** can now handle a single oil tank with sets of PVT varying with depth.

Version 3.5 - Release 20:

MBAL Version 3.5 - Enhancements Implemented:

All tools

Data Import

- The data import section has been enhancement to accept from several data sources. **MBAL** can now import data from :
  - ASCII files,
  - ODBC Databases,
  - Dwights Production Data CD-ROM's.

Material Balance

Gas Cap Production

- **MBAL** can now handle the primary gas cap production in the production forecast. Gas zone and oil zone can now be produced separately. See the gas Cap production on option in the Options dialogue

Field Potential Calculation

- **MBAL** can now calculate the potential of gas and retrograde fields against the minimum manifold pressure constraint during the prediction run. An extra column has been added to the prediction result screen. See the Prediction Set-up dialogue

Correction of IPR for water cut

- The PI+Vogel IPR has been modified to take into account the change of PI due to the change in WC and the change of mobility of the liquid. The program uses the relative permeabilities to evaluate the change in mobility. See the Use Relative Permeabilities option in the IPR input screen

Decline Curve Analysis

Well by Well matching

- The program can now match the decline of several wells and run a prediction on the totality of the wells

Version 3.0 - Release 1:

MBAL Version 3.0 - Enhancements Implemented:

MBAL is now available under MS-Windows and Unix-XWindows.

All Tools

Structure changes

- In the past two years, the original material balance program has evolved into a more sophisticated forecasting program, requiring more and more input, tables, and result arrays. Because of the simple structure of the program, the memory and disk space requirements where becoming excessive. For this reason, the program and its files has been completely restructured

Memory

- All the tables have a variable length. This means that only the memory required to hold the data input is allocated. It also means that there is now no limitation on the length of any table (production history, PVT, relative permeabilities, calculation result, ...) apart from the amount of memory available under MS-Windows or XWindows (which can be substantial when a memory swap file is in use). This new structure also give more flexibility to the data handling routines. For example the contents of ‘spreadsheet like’ data input screens and reports can now be customised. The program now also offers a flexible and programmable ‘import filter’ feature. (see import filters below)

Files

- The data files have been optimised and are in average 10 times smaller than the previous ones. The data files are also platform independent, i.e. the same data file can be read with the MS-Windows or Unix-XWindows versions

  But be careful ! : The data file are not backward compatible. **MBAL** will display a warning message before overwriting a data file that has been saved with a previous version of the program.

Data Import Feature

- A flexible and programmable import 'filter' has been added to most tables. The new option allows the user to read data from any ASCII file and lets him select data on the screen. A template of the user defined import 'filter' can then be saved to disk to be re-used. The saved template will automatically appear in the list of import file type available. Templates are saved to disk into individual files (extension .MBQ). This allows customised templates to be defined and distributed with the program within an organisation

Result screens

- Most result screens can now be customised i.e. the user can selected the list of columns to be displayed. The masking selection can be switched on and off at the pressing of a button

Result reports

- Most result reports can also be customised i.e. the user can selected the list of columns to be reported. The selection screen is accessed by clicking on the ▼ button next to the report descriptor

Material Balance tool

Sweep Efficiency

- Gas and water sweep efficiency have been split. There is now an entry for both. This will only affect the contact depth calculations

Oil residual saturation

- The oil residual saturation has also been split between gas flooding (gas cap influx or gas injection) and water flooding (aquifer influx or water injection). This will only affect the contact depth calculations

Voidage replacement

- The program can now handle automatically voidage replacement by gas or water. Any percentage of the voidage can be replaced at any time (i.e. the voidage replacement can be switch on and off at will. The percentage of voidage replacement appears has a variable in the production and constraint screen

Gas contract calculations

- A new prediction mode is now available for gas contract calculations (see DCQ prediction 283).
    - **Tubing performance for dry gas wells** : Two **dry gas** tubing pressure loss correlations have been implemented. These correlations can be used in place of the Tubing Performance Curve for quick evaluation of prospects. The correlations can be also matched on test data. Note that using these correlations slow down the calculations and

are usually of mediocre qualities compared to a good set of tubing performance curves. **These correlations are not to be used if the well produces any trace of liquid**

Version 2.5 - Release 4:

MBAL Version 2.5 - Enhancements Implemented:

Material Balance tool

New Aquifer Model

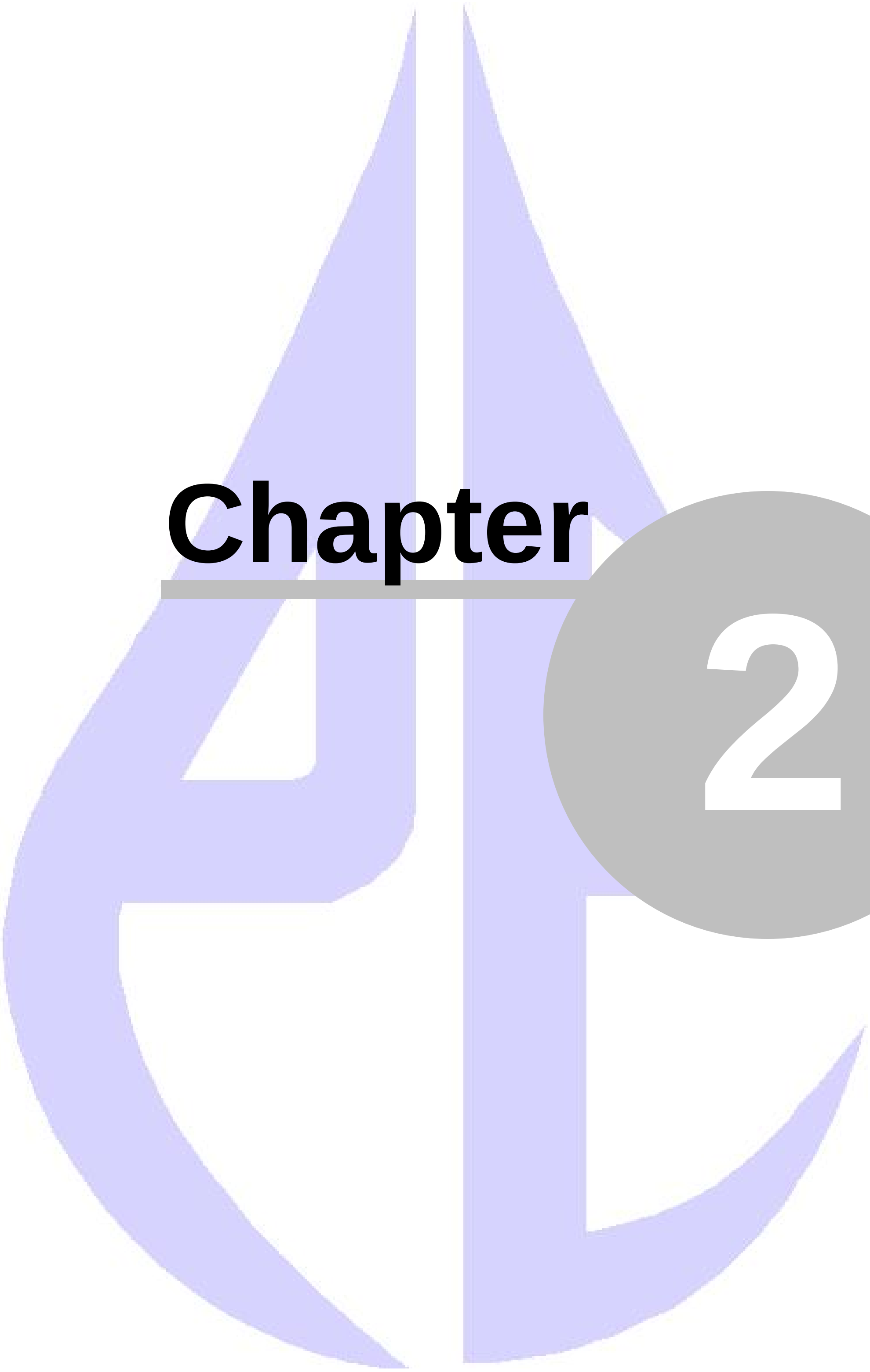
- The ‘Hurst and van Everdingen modified’ aquifer model has been added (see Water Influx)

New Prediction Constraints

- Constraints on water and gas production have been added to all prediction modes (see production and constraints)

Change in calculations

- **The handling of the vertical sweep efficiency has been changed**. In the previous release, the vertical sweep efficiency was wrongly affecting the relatives permeability by shifting the residual saturations and end points. One of the main effect of this, was that the production of oil would stop when the water contact reached the top of the reservoir. In the current release, the vertical sweep efficiency is only used in the calculation of the depth of the contacts. The relatives permeabilities are not affected. This allows production of oil even after the oil water contact has reached the top of the reservoir



Chapter

2

2 User Guide

MBAL is Windows based software. The screen displays used in this guide are taken from the examples provided with the software. On occasion, the data files may vary from the examples shown as updates to the program are issued. Where major amendments or changes to the program require further explanation, the corresponding documentation will be provided.

Before a modelling exercise, the objectives of the exercise should be defined. Once the objectives are defined, the chapters in this document are organised to correspond with the steps one might follow to set-up an **MBAL** model in order to achieve the objectives.

This user guide will define the workflow and logic required for each step required to model different systems. The following chapters will cover all the steps:

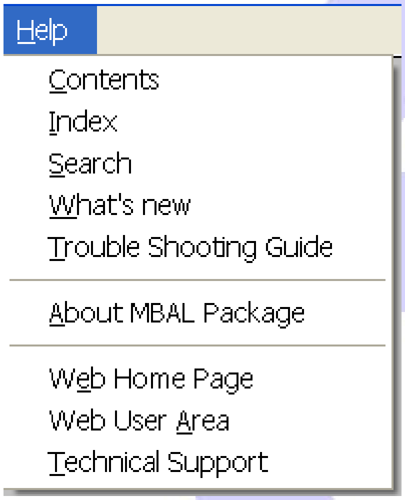
Getting help 29	This chapter describes how to find the software documentation and how to contact *Petroleum Experts* technical support
Using the MBAL Application 30	This chapter illustrates the main features of saving/opening files, preferences, etc.
Data Input and Import 45	This chapter describes how to input data in the program or import them from an external source. A description of the options available and PVT data required is provided
The Material Balance Tool 154	This chapter illustrates the Material Balance tool of **MBAL**, from the input data to the history matching and prediction calculations
Reservoir 344 **Allocation Tool** 344	This chapter illustrates the Reservoir Allocation tool of **MBAL**, from the input data to the history matching and allocating the production of each well to its reservoir and prediction calculations
Monte-Carlo Technique 361	This chapter illustrates the usage of the Monte Carlo tool to perform statistical estimations of fluid in place
Decline Curve Analysis 369	This chapter describes the Decline Curve Analysis tool
1D Model 383	This chapter describes the 1D Model tool and 1D model with EOR
Multi Layer Tool 409	This chapter describes the Multi Layer tool
Tight Gas Type Curve Tool 421	This chapter describes the Tight Gas Type Curve analysis tool, from history matching the production to using the model for forward predictions
Streamlines 448	This chapter describes the streamline tool in MBAL
Appendix 458	The Appendix contains chapters on references, equations used by **MBAL** and troubleshooting guide

Depending on the needs and the amount of time available to the user to become familiar with the program, this guide may be used in different ways. The step by step examples of the Examples Guide 512 provide a detailed account of building Material Balance models and performing predictions. If more details on any of the options are required, then the various chapters relevant to the options in question can be consulted.

If the user is new to Windows applications, it is recommended that the whole guide be read to become familiar with the program features, menus, and options.
This is the slow approach, but will cover all that needs to be known about the program ensuring that a full understanding of the software usage and functionality has been obtained.

2.1 Getting Help

MBAL has an on-line help facility that allows quick access to information about a menu option, input field or function command without leaving the **MBAL** screen.



To use this facility, the help file must be located in the same directory as the program.

The help facility uses function buttons and jump terms to move around the 'Help' system. The function buttons are found at the top of the window and are useful in finding general information about Windows help. If a feature is not available, the button associated with that function is dimmed.

'Jump' terms are words marked with a solid underline that appear in green if a colour VDU is in use. Clicking on a jump term, takes the user directly to the topic associated with the underlined word(s).

Finding information in 'Help'.
There are several ways of getting the required information:

Using the Help Index	This option is useful for viewing specific sections listed in the help menu. Go to the topic of interest and select the necessary subject item
Using the Help Search feature	This facility is useful for finding specific information about particular topics. For example, 'Production Constraints'. Type in the keyword 'constraints' to search the system for the phrase, or select the corresponding topic from the list displayed

2.1.1 Accessing Help

To get information quickly in **MBAL**, the following methods display the on-line help.

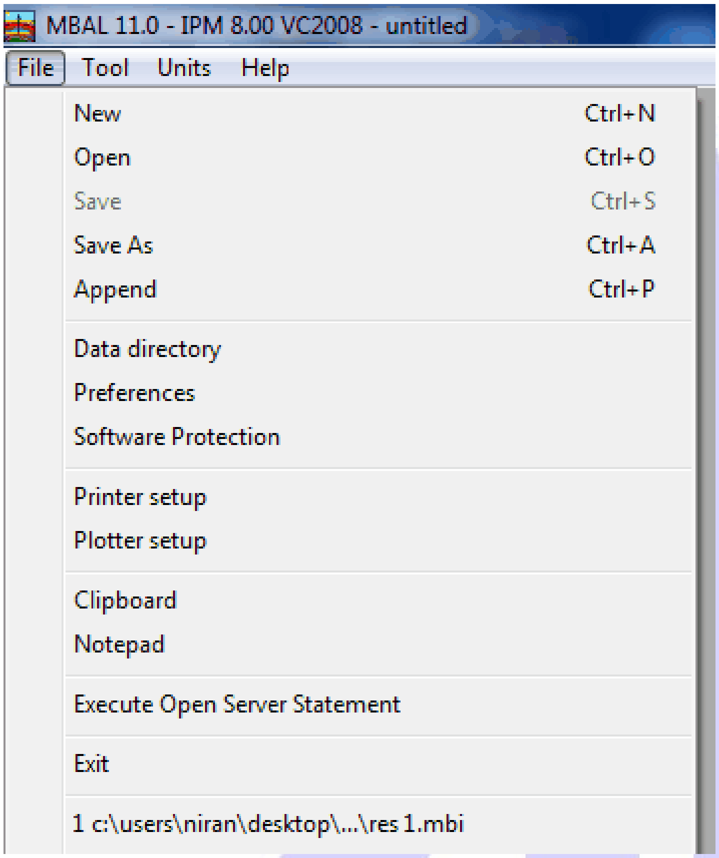
Help through the menu	From the menu bar, choose **Help | Index** or **ALT H I**, and select the desired subject from the list of help topics provided
Getting help using the mouse and keyboard	To get help through the mouse, Press **SHIFT+F1**. The mouse pointer changes to a question mark. Next, choose the menu command or option to view. An alternative way is to click the menu command or option to view, and holding the mouse button down, press **F1**. To get help using the keyboard press the **ALT** key followed by the first letter of the menu name or option and press **F1**
Minimising Help	If the Help window is to be closed, but not exiting the help facility, click the minimise button in the upper-right corner of the help window. If use of the keyboard is preferred, press **ALT** Spacebar **N**

2.2 Using the MBAL application

For first time users, this chapter covers the essential features of data management. In addition to the **MBAL** procedures used to open, save and print files, this chapter also describes the procedures to establish links to other Windows programs, define the system units and getting help. The options and procedures discussed in the following sections are found under the; File, Units, and Help menus.

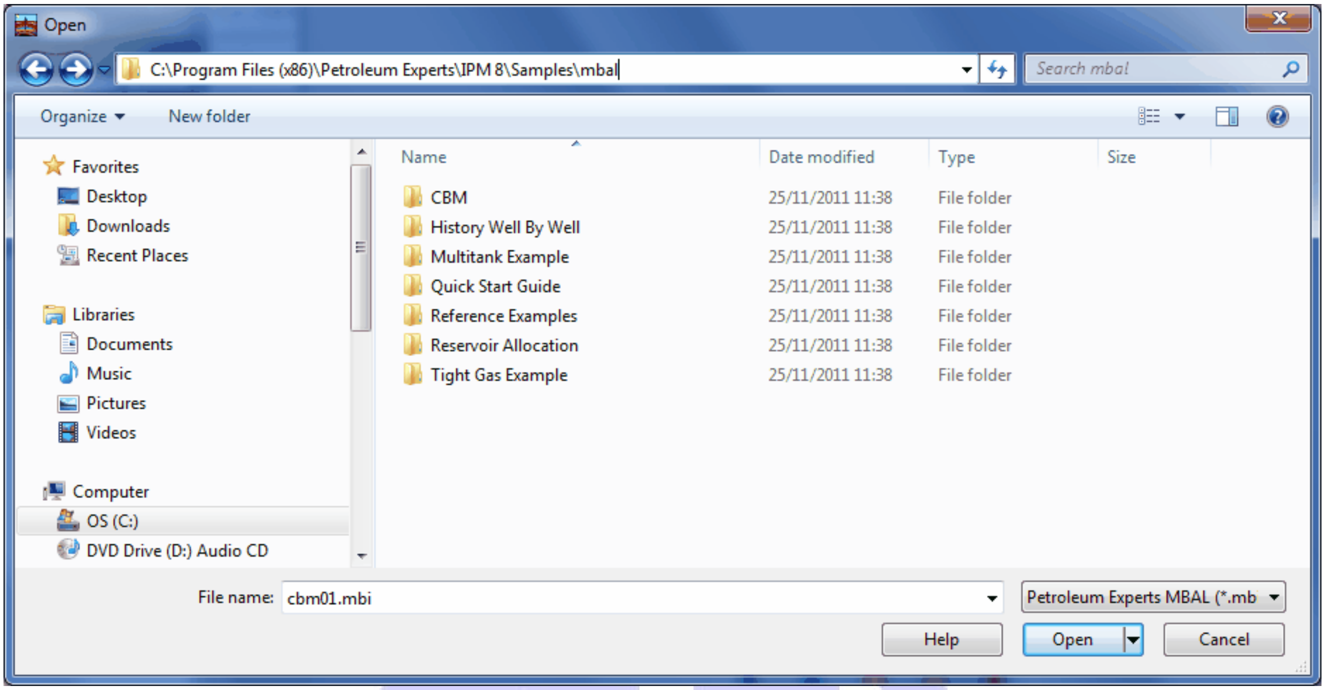
2.2.1 File Management

The following sections describe the 'File' menu commands:


MBAL 11.0 - IPM 8.00 VC2008 - untitled
File
Tool
Units
Help
New Ctrl+N
Open Ctrl+O
Save Ctrl+S
Save As Ctrl+A
Append Ctrl+P
Data directory
Preferences
Software Protection
Printer setup
Plotter setup
Clipboard
Notepad
Execute Open Server Statement
Exit
1 c:\users\niran\desktop\...\res 1.mbi

2.2.1.1 Opening and Saving Files

When **MBAL** is first started, the program automatically opens the last file which was accessed. If the file which is first viewed is not the one which is to be worked with, other data files can be opened quickly and easily at any time during the current working session. To open a specific file, choose File|Open, or press Ctrl+O. The following screen will then be displayed:



C:\Program Files (x86)\Petroleum Experts\IPM 8\Samples\mbal

Name	Date modified	Type	Size
CBM	25/11/2011 11:38	File folder	
History Well By Well	25/11/2011 11:38	File folder	
Multitank Example	25/11/2011 11:38	File folder	
Quick Start Guide	25/11/2011 11:38	File folder	
Reference Examples	25/11/2011 11:38	File folder	
Reservoir Allocation	25/11/2011 11:38	File folder	
Tight Gas Example	25/11/2011 11:38	File folder	

File name: cbm01.mbi

Petroleum Experts MBAL (*.mb

A dialogue box appears listing in alphabetical order. The files in the default data directory are automatically shown first. A file can be opened as for any Windows application.

The standard **MBAL** file type is the *.MBI file. This type is displayed by default. The only other file type available is the .MBR file. This is an output file from **GAP** which stores the GAP forecast results to be read in **MBAL**.

Saving files can be done as for any Windows application.

Use 'Save As' command to make more than one copy or version of a file. While working with the program, this command is useful for saving trial runs of the work. The 'Save As' command allows the user to:

- Save a file under the same name but to a different drive, or
- Save a file under a different name on the same drive.

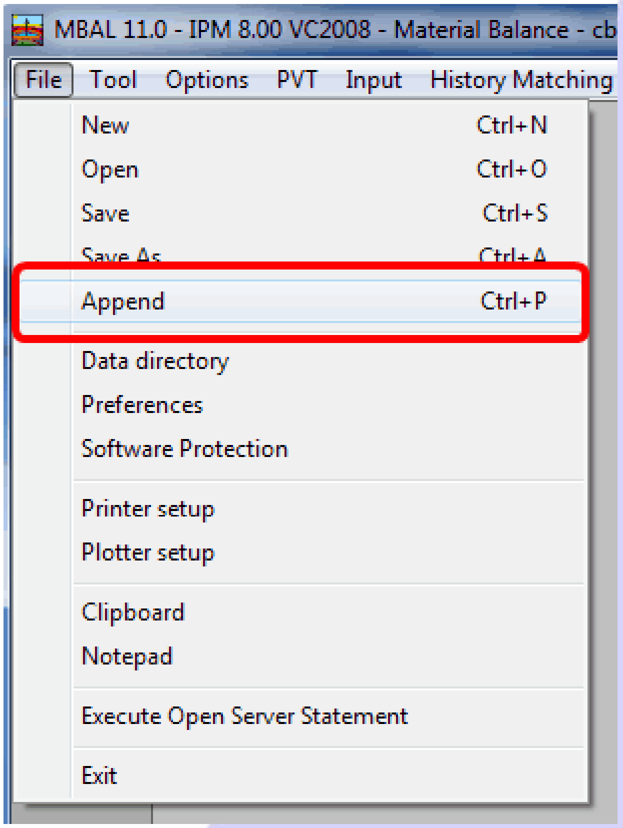
Before saving a copy to another disk or medium, we recommend the original file is first saved on the hard disk. To make a file copy choose:

File | Save As or **Ctrl+A**

When copying a file, the default data directory is automatically displayed first. If a file name which already exists is entered to 'Save As', the program asks if the user wishes to replace the file. Selecting 'Yes' will replace the existing file while selecting 'No' allows a new name to be selected. To copy a file, enter a new name in the File Name field and press ***Enter*** or click ***Done***.

2.2.1.2 Append

This option allows the user to merge different **MBAL** files:


MBAL 11.0 - IPM 8.00 VC2008 - Material Balance - cb
File
Tool
Options
PVT
Input
History Matching
New Ctrl+N
Open Ctrl+O
Save Ctrl+S
Save As Ctrl+A
Append Ctrl+P
Data directory
Preferences
Software Protection
Printer setup
Plotter setup
Clipboard
Notepad
Execute Open Server Statement
Exit

This can be useful in cases in which users have created **MBAL** files for reservoirs independently and then require all of them in the same **MBAL** file.

This option allows the user to read objects from a file and append them to the current **MBAL** data set without deleting current data. The objects that may be appended include:

- **tanks**
- **history and prediction wells**
- **transmissibilities**
- **PVT data**

This option is only available if the 'material balance' tool is in use as multiple objects are not allowed in the other tools. Note also that since variable PVT can only be used for single tank mode, the append option cannot be used if **MBAL** is in variable PVT mode or the file to be appended used variable PVT.

It is important to note that the only data which can be appended is described in the list above. Further data such as; drilling schedule, production constraints, prediction results cannot be appended.

Select the file to append from the file open dialogue as usual.

All the names of the objects in **MBAL** at any one time must be unique. If there are any conflicts between the names of objects in the file to append and those already in **MBAL**, the user will be asked to enter new names.

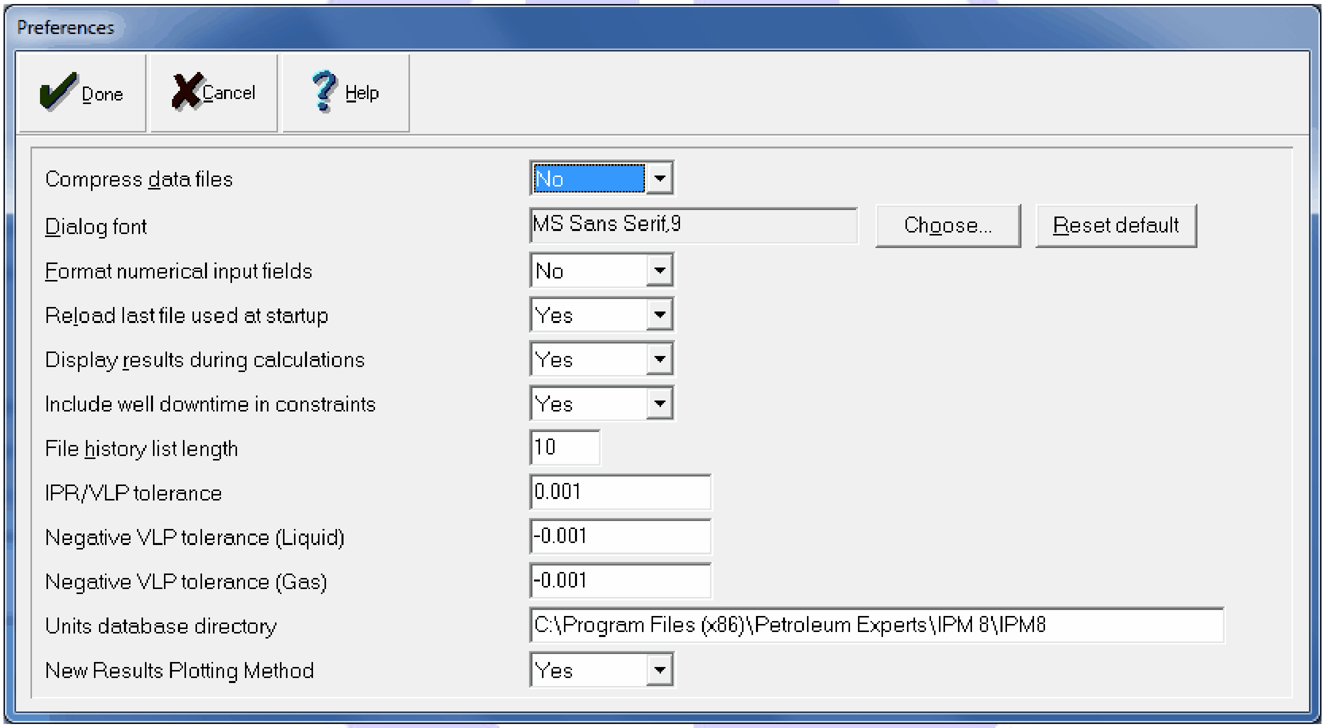
At the end of the procedure, the user will then be asked if auto-arranging is to be applied to the main graphical display. If it is not applied; the appended objects may lie on top of existing objects and the user will then need to use the **Move** tool to arrange them correctly.

2.2.1.3 Defining the Working Directory

The 'Data Directory option' specifies the default working directory where files will be saved in and picked up from. This facility makes it more efficient to access data files. Whenever a new file is opened, closed or created, the program automatically selects the files to open or saves to the directory defined here.

2.2.1.4 Preferences

The 'Preferences' option allows setting various **MBAL** preferences.



Compress data files: No
Dialog font: MS Sans Serif,9
Format numerical input fields: No
Reload last file used at startup: Yes
Display results during calculations: Yes
Include well downtime in constraints: Yes
File history list length: 10
IPR/VLP tolerance: 0.001
Negative VLP tolerance (Liquid): -0.001
Negative VLP tolerance (Gas): -0.001
Units database directory: C:\Program Files (x86)\Petroleum Experts\IPM 8\IPM8
New Results Plotting Method: Yes

These include:

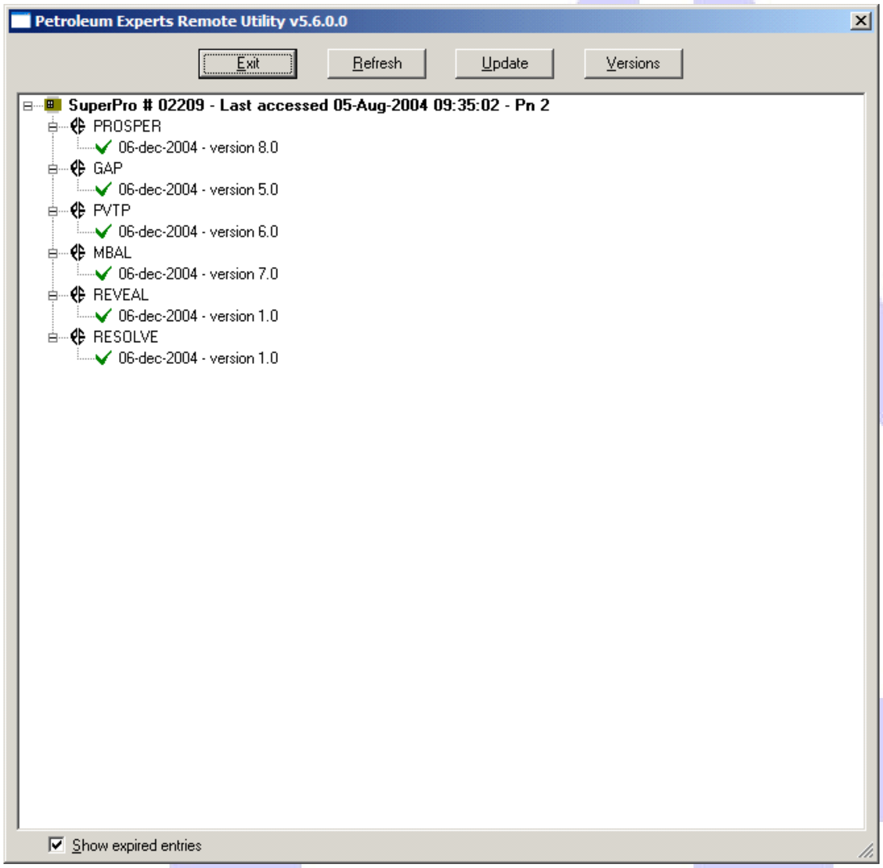
Compress Data Files	Select yes to compress (zip) data files when saving to disk. This facility is useful for managing very large data files

Dialogue Font	This changes the screen display, font type and size. Only fonts installed under Windows are displayed. Refer to the Windows manual for more information on the installation of fonts
Format Numerical Input Fields	This option specifies how the numerical input fields are displayed. If this is set to 'Yes', numbers will be displayed with a fixed number of digits e.g. 0.3000 or 12.00. Also the number is centred within the field. If this option is set to 'No', numbers will be displayed with as few digits as necessary e.g. 0.3 or 12. Also the number is left justified within the field
Reload Last File Used at Startup	If 'Yes' is selected **MBAL** will load the file that was last in use. If 'No' is selected, **MBAL** will not load any file when it starts
File History List Length	The file menu normally keeps a list of the last files that were accessed by **MBAL**. This entry allows the number of files appearing in the list to be user controlled, the maximum number of files being 10.
Display Results during Calculations	If 'No' is selected, **MBAL** will not update the dialogues with the results until the end of the prediction and simulation calculations. This will mean that the calculation progress will not be visible. However, it will speed up the calculations by up to 25%
Include Well Downtime in Constraints	If the downtime applied to wells in a production system is known, this can be included in the well description section of MBAL. However, should this information be discounted for the model, i.e. define the rate without factoring by the well downtime, this option can be switched off
IPR/VLP Tolerance	This value can be used to control the tolerance used in the calculation of VLP/IPR intersections. The tolerance used in the calculation is the average layer pressure multiplied by the value displayed in this field. For example, if a value of 0.001 is entered, the tolerance in use will be 0.1% of the average layer pressure. The default value of 0.001 will calculate the majority of intersections accurately and keep calculation times at a reasonable level. However some cases (particularly with high PIs) may require a smaller tolerance to give better results, it should be noted however, that calculation times would be increased
Negative VLP Tolerance (Liquid)	Should the negative slope of the VLP intersect with the IPR (resulting in unstable production) the user is able to define whether such an intersection is considered as the system production rate by varying the numerical value. This value is applied to oil or water wells, it is not applied to injectors. If 0.0 is entered then **MBAL** will not allow any solutions where the slope of the VLP is negative. If a negative value is entered, then **MBAL** will check if the slope of the VLP at the solution is less than the entered value. If it is, then the rate will be set to 0. In other words, if a very large negative value is entered, such as -1.0e10, then **MBAL** will allow any negative slope. The program does not allow a positive number to be entered to exclude

	small positive VLP slopes
Negative VLP Tolerance (Gas)	This is exactly the same as 'Negative VLP Tolerance (Liquid)' above except that it applies to gas producer wells.
Units Database Directory	This field specifies the directory where the units database for **MBAL** is located.
New Results Plotting Method	***New to IPM8.0*** This feature allows the user to revert between the old plotting and new plotting preferances

2.2.1.5 Viewing the Software Key

The 'Software Protection' command activates the REMOTE software utility program that allows access to the software protection key. The REMOTE facility indicates which of the programs are enabled on the key, the program expiration date, and the key and client number. This utility is also used to activate the key when the program licence has date has expired, or to update the key when more program modules are acquired.



- SuperPro # 02209 - Last accessed 05-Aug-2004 09:35:02 - Pn 2
  - PROSPER
    - ✓ 06-dec-2004 - version 8.0
  - GAP
    - ✓ 06-dec-2004 - version 5.0
  - PVTP
    - ✓ 06-dec-2004 - version 6.0
  - MBAL
    - ✓ 06-dec-2004 - version 7.0
  - REVEAL
    - ✓ 06-dec-2004 - version 1.0
  - RESOLVE
    - ✓ 06-dec-2004 - version 1.0

2.2.1.6 Selecting Printers and Plotters

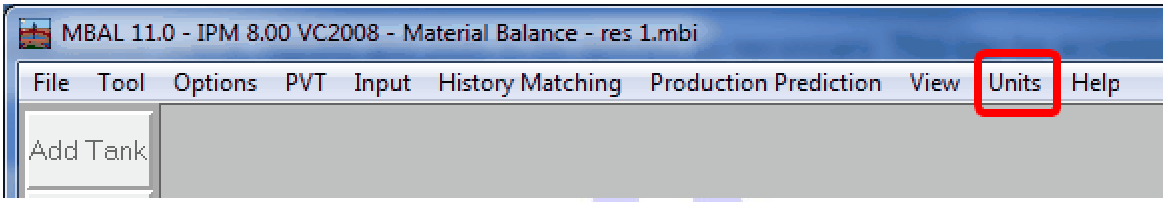
Use these menu options to select the output (printer or plotter) devices.

2.2.1.7 Windows Notepad

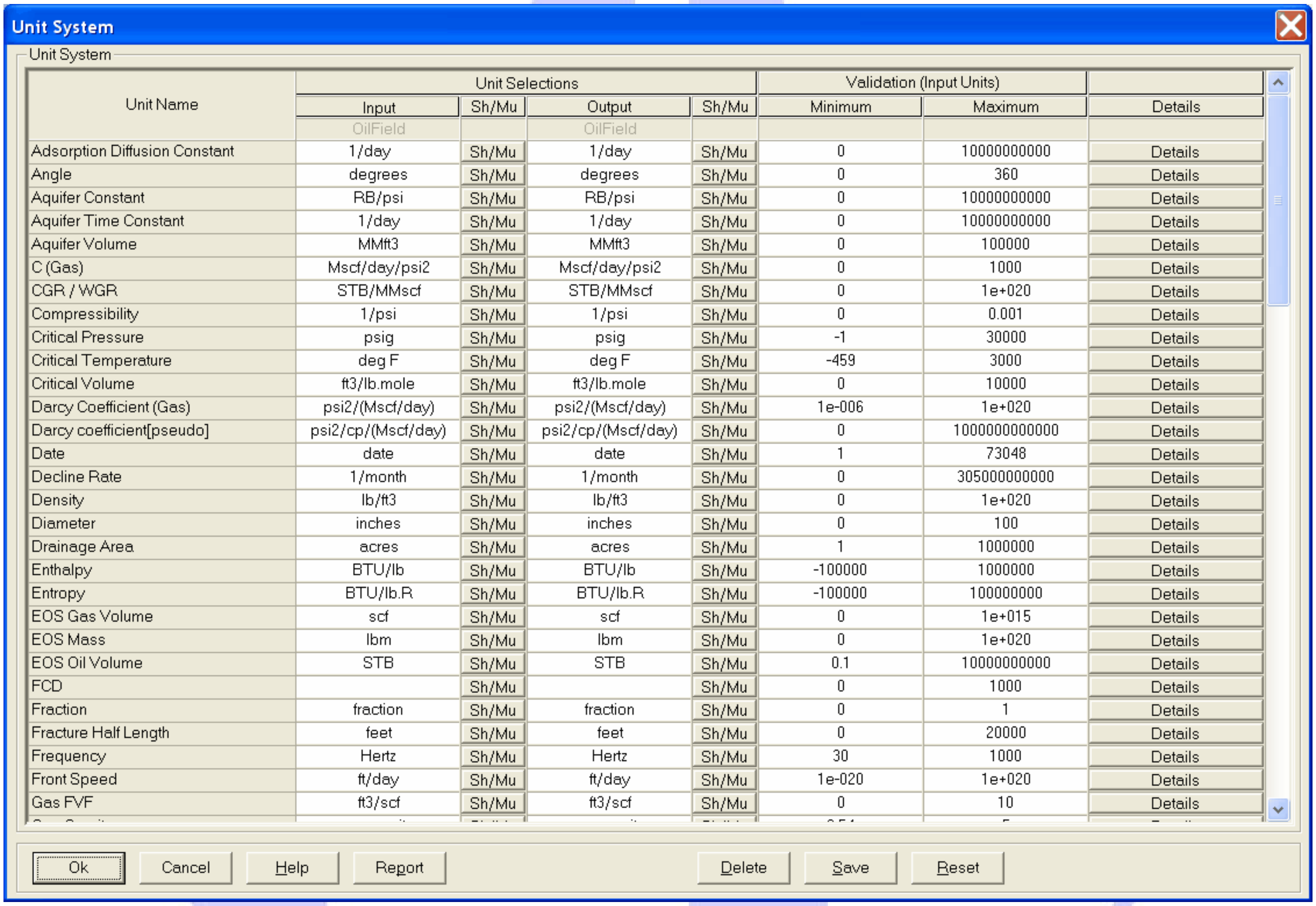
The 'Notepad' command provides direct access to the Windows text editor. This application is useful to make notes of current analysis for later inclusion in reports. This option can also be used view the results of calculations that have been saved to a file.

2.2.2 Setting the Units

The 'Units' menu allows the measurement units used in; dialogue boxes, calculation output, reports and plots to be defined as necessary. This can be accessed as shown below:



The following screen will appear:



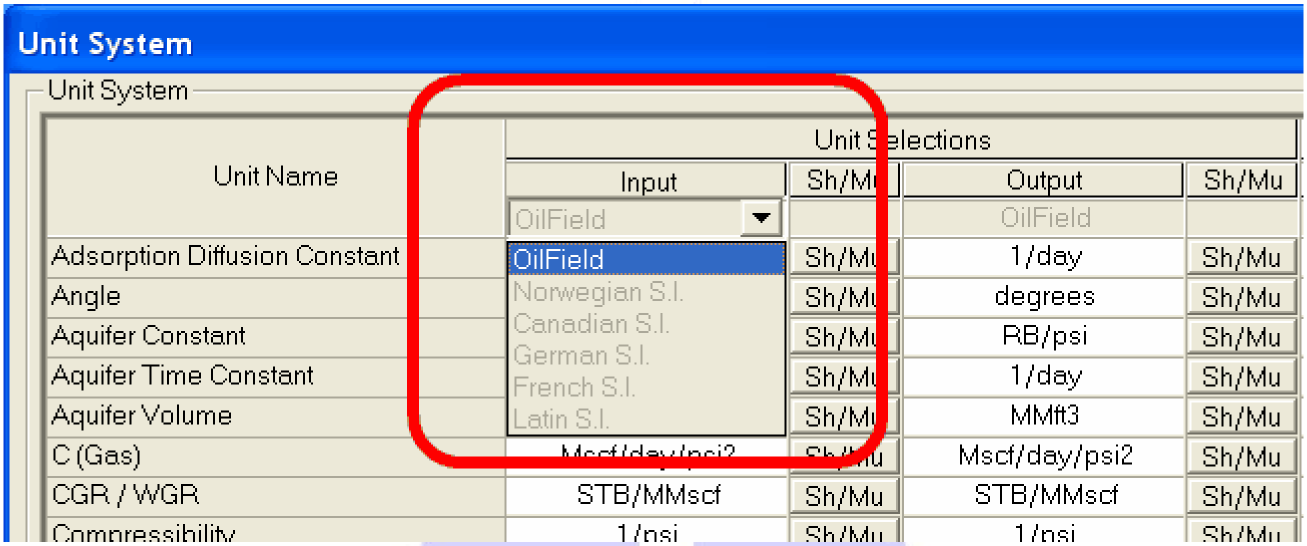
Unit Name	Unit Selections				Validation (Input Units)		
	Input	Sh/Mu	Output	Sh/Mu	Minimum	Maximum	Details
	OilField		OilField				
Adsorption Diffusion Constant	1/day	Sh/Mu	1/day	Sh/Mu	0	10000000000	Details
Angle	degrees	Sh/Mu	degrees	Sh/Mu	0	360	Details
Aquifer Constant	RB/psi	Sh/Mu	RB/psi	Sh/Mu	0	10000000000	Details
Aquifer Time Constant	1/day	Sh/Mu	1/day	Sh/Mu	0	10000000000	Details
Aquifer Volume	MMft3	Sh/Mu	MMft3	Sh/Mu	0	100000	Details
C (Gas)	Mscf/day/psi2	Sh/Mu	Mscf/day/psi2	Sh/Mu	0	1000	Details
CGR / WGR	STB/MMscf	Sh/Mu	STB/MMscf	Sh/Mu	0	1e+020	Details
Compressibility	1/psi	Sh/Mu	1/psi	Sh/Mu	0	0.001	Details
Critical Pressure	psig	Sh/Mu	psig	Sh/Mu	-1	30000	Details
Critical Temperature	deg F	Sh/Mu	deg F	Sh/Mu	-459	3000	Details
Critical Volume	ft3/lb.mole	Sh/Mu	ft3/lb.mole	Sh/Mu	0	10000	Details
Darcy Coefficient (Gas)	psi2/(Mscf/day)	Sh/Mu	psi2/(Mscf/day)	Sh/Mu	1e-006	1e+020	Details
Darcy coefficient[pseudo]	psi2/cp/(Mscf/day)	Sh/Mu	psi2/cp/(Mscf/day)	Sh/Mu	0	1000000000000	Details
Date	date	Sh/Mu	date	Sh/Mu	1	73048	Details
Decline Rate	1/month	Sh/Mu	1/month	Sh/Mu	0	305000000000	Details
Density	lb/ft3	Sh/Mu	lb/ft3	Sh/Mu	0	1e+020	Details
Diameter	inches	Sh/Mu	inches	Sh/Mu	0	100	Details
Drainage Area	acres	Sh/Mu	acres	Sh/Mu	1	1000000	Details
Enthalpy	BTU/lb	Sh/Mu	BTU/lb	Sh/Mu	-100000	1000000	Details
Entropy	BTU/lb.R	Sh/Mu	BTU/lb.R	Sh/Mu	-100000	100000000	Details
EOS Gas Volume	scf	Sh/Mu	scf	Sh/Mu	0	1e+015	Details
EOS Mass	lbm	Sh/Mu	lbm	Sh/Mu	0	1e+020	Details
EOS Oil Volume	STB	Sh/Mu	STB	Sh/Mu	0.1	10000000000	Details
FCD		Sh/Mu		Sh/Mu	0	1000	Details
Fraction	fraction	Sh/Mu	fraction	Sh/Mu	0	1	Details
Fracture Half Length	feet	Sh/Mu	feet	Sh/Mu	0	20000	Details
Frequency	Hertz	Sh/Mu	Hertz	Sh/Mu	30	1000	Details
Front Speed	ft/day	Sh/Mu	ft/day	Sh/Mu	1e-020	1e+020	Details
Gas FVF	ft3/scf	Sh/Mu	ft3/scf	Sh/Mu	0	10	Details

2.2.2.1 Defining System Units

In **MBAL**, the units can be changed or selected at two levels. These are at the **MBAL** global level or at an individual variable level.

2.2.2.2 Defining the Global Unit System

A particular unit system can be selected from the drop-down list boxes at the top of the unit columns. This will change the default units for all variables in **GAP**. The options available are shown below:

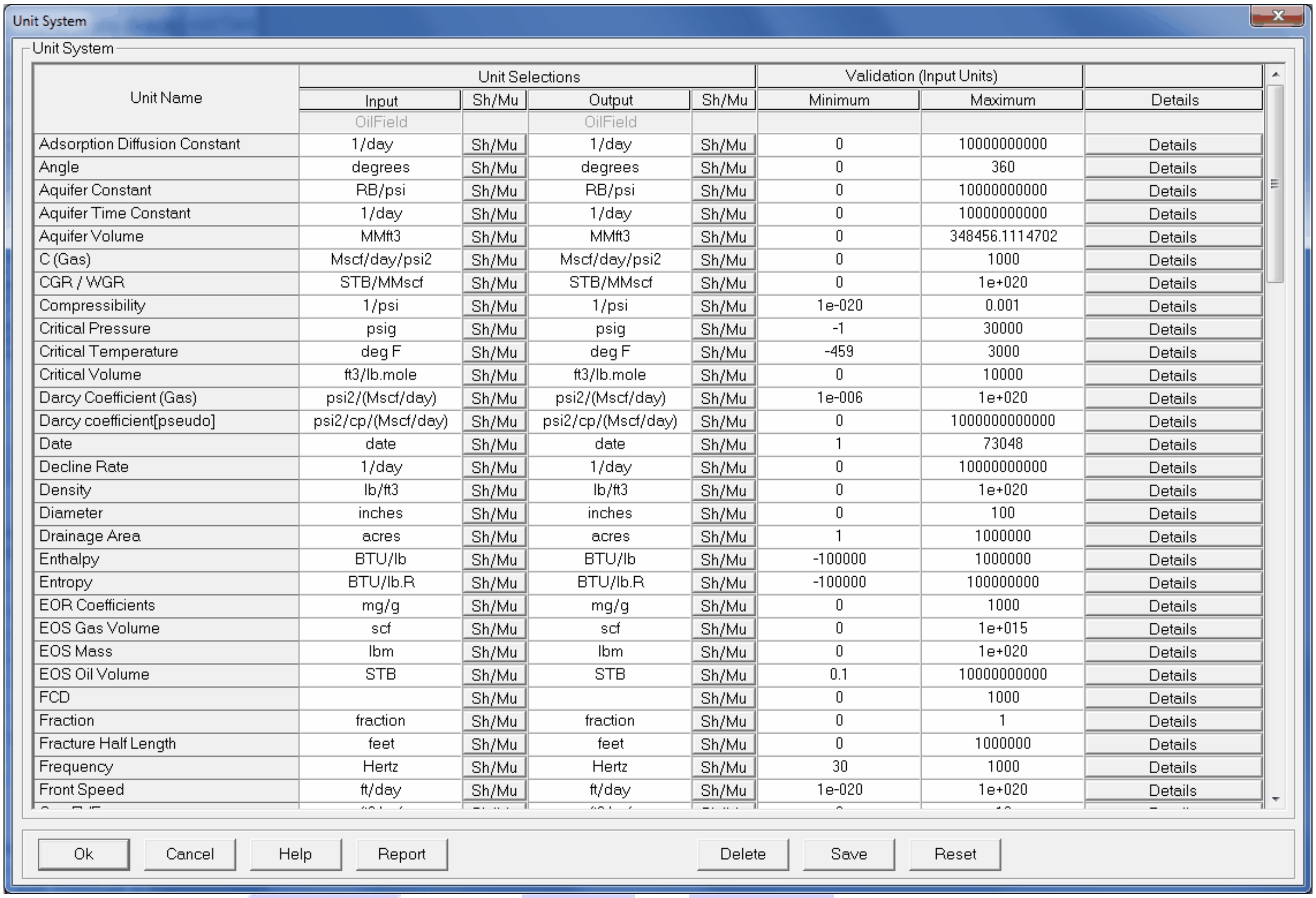


Unit Name	Unit Selections Input	Sh/Mu	Output	Sh/Mu
	OilField		OilField	
Adsorption Diffusion Constant		Sh/Mu	1/day	Sh/Mu
Angle		Sh/Mu	degrees	Sh/Mu
Aquifer Constant		Sh/Mu	RB/psi	Sh/Mu
Aquifer Time Constant		Sh/Mu	1/day	Sh/Mu
Aquifer Volume		Sh/Mu	MMft3	Sh/Mu
C (Gas)	Mscf/day/psi2	Sh/Mu	Mscf/day/psi2	Sh/Mu
CGR / WGR	STB/MMscf	Sh/Mu	STB/MMscf	Sh/Mu
Compressibility	1/psi	Sh/Mu	1/psi	Sh/Mu

2.2.2.3 Changing individual variable units

It is also possible to change the units of individual variables in **MBAL** to generate a user specific set of units that can be saved and picked up later in other **MBAL** models. To change units of individual variables and create a mixed set of units follow the steps below.

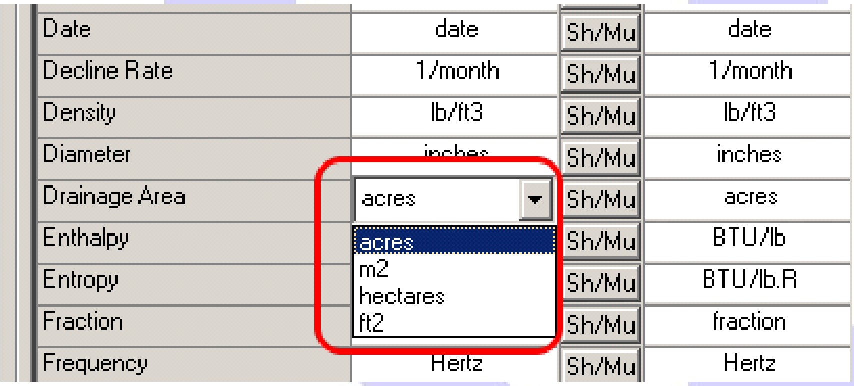
To view and select the variables, move the scroll bar thumb in any direction, up or down until the desired variable has been located.



Unit System

Unit Name	Unit Selections				Validation (Input Units)		
	Input	Sh/Mu	Output	Sh/Mu	Minimum	Maximum	Details
	OilField		OilField				
Adsorption Diffusion Constant	1/day	Sh/Mu	1/day	Sh/Mu	0	10000000000	Details
Angle	degrees	Sh/Mu	degrees	Sh/Mu	0	360	Details
Aquifer Constant	RB/psi	Sh/Mu	RB/psi	Sh/Mu	0	10000000000	Details
Aquifer Time Constant	1/day	Sh/Mu	1/day	Sh/Mu	0	10000000000	Details
Aquifer Volume	MMft3	Sh/Mu	MMft3	Sh/Mu	0	348456.1114702	Details
C (Gas)	Mscf/day/psi2	Sh/Mu	Mscf/day/psi2	Sh/Mu	0	1000	Details
CGR / WGR	STB/MMscf	Sh/Mu	STB/MMscf	Sh/Mu	0	1e+020	Details
Compressibility	1/psi	Sh/Mu	1/psi	Sh/Mu	1e-020	0.001	Details
Critical Pressure	psig	Sh/Mu	psig	Sh/Mu	-1	30000	Details
Critical Temperature	deg F	Sh/Mu	deg F	Sh/Mu	-459	3000	Details
Critical Volume	ft3/lb.mole	Sh/Mu	ft3/lb.mole	Sh/Mu	0	10000	Details
Darcy Coefficient (Gas)	psi2/(Mscf/day)	Sh/Mu	psi2/(Mscf/day)	Sh/Mu	1e-006	1e+020	Details
Darcy coefficient[pseudo]	psi2/cp/(Mscf/day)	Sh/Mu	psi2/cp/(Mscf/day)	Sh/Mu	0	1000000000000	Details
Date	date	Sh/Mu	date	Sh/Mu	1	73048	Details
Decline Rate	1/day	Sh/Mu	1/day	Sh/Mu	0	10000000000	Details
Density	lb/ft3	Sh/Mu	lb/ft3	Sh/Mu	0	1e+020	Details
Diameter	inches	Sh/Mu	inches	Sh/Mu	0	100	Details
Drainage Area	acres	Sh/Mu	acres	Sh/Mu	1	1000000	Details
Enthalpy	BTU/lb	Sh/Mu	BTU/lb	Sh/Mu	-100000	1000000	Details
Entropy	BTU/lb.R	Sh/Mu	BTU/lb.R	Sh/Mu	-100000	100000000	Details
EOR Coefficients	mg/g	Sh/Mu	mg/g	Sh/Mu	0	1000	Details
EOS Gas Volume	scf	Sh/Mu	scf	Sh/Mu	0	1e+015	Details
EOS Mass	lbm	Sh/Mu	lbm	Sh/Mu	0	1e+020	Details
EOS Oil Volume	STB	Sh/Mu	STB	Sh/Mu	0.1	10000000000	Details
FCD		Sh/Mu		Sh/Mu	0	1000	Details
Fraction	fraction	Sh/Mu	fraction	Sh/Mu	0	1	Details
Fracture Half Length	feet	Sh/Mu	feet	Sh/Mu	0	1000000	Details
Frequency	Hertz	Sh/Mu	Hertz	Sh/Mu	30	1000	Details
Front Speed	ft/day	Sh/Mu	ft/day	Sh/Mu	1e-020	1e+020	Details

The corresponding input and output unit categories will scroll simultaneously. From the appropriate unit category (Input/Output), select the preferred measurement unit for the unit selected. To view the list of units click the arrow to the right of the field. To select a unit, click the name to highlight the item:

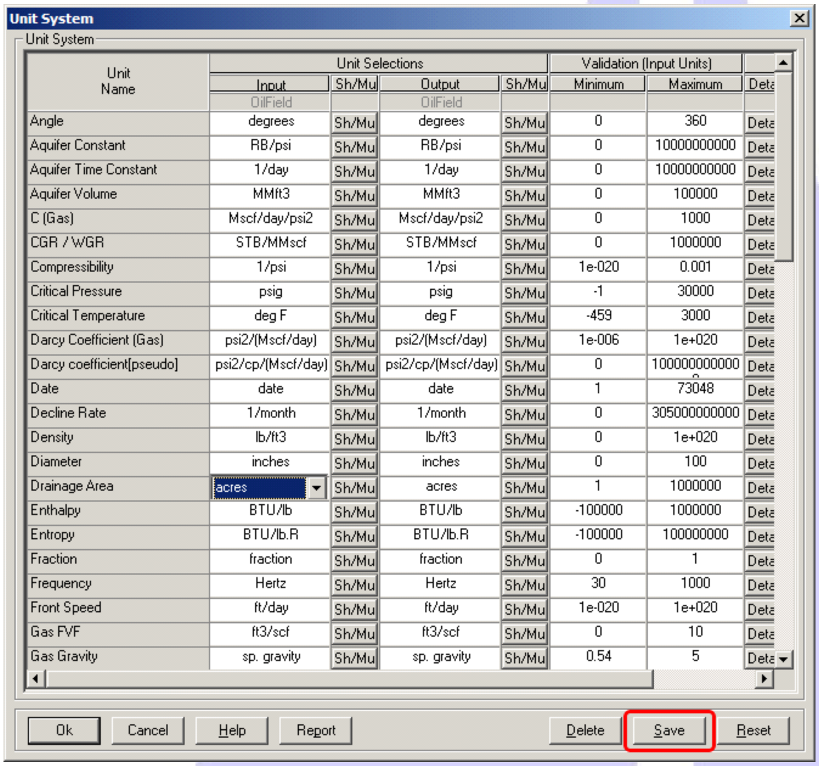


Date	date	Sh/Mu	date
Decline Rate	1/month	Sh/Mu	1/month
Density	lb/ft3	Sh/Mu	lb/ft3
Diameter	inches	Sh/Mu	inches
Drainage Area	acres	Sh/Mu	acres
Enthalpy		Sh/Mu	BTU/lb
Entropy		Sh/Mu	BTU/lb.R
Fraction		Sh/Mu	fraction
Frequency	Hertz	Sh/Mu	Hertz

To view the conversion between the currently selected unit and the base (default) unit for the variable in question, click the blank button to the right of the units drop down list.

Note that a change to the input or output units in the unit database is global with respect to that variable, and will affect entries made in the variable database (accessed from the Controls button). For example, a change in the input unit of Pressure will affect, among others, the Layer Pressure in the Well IPR Input screen.

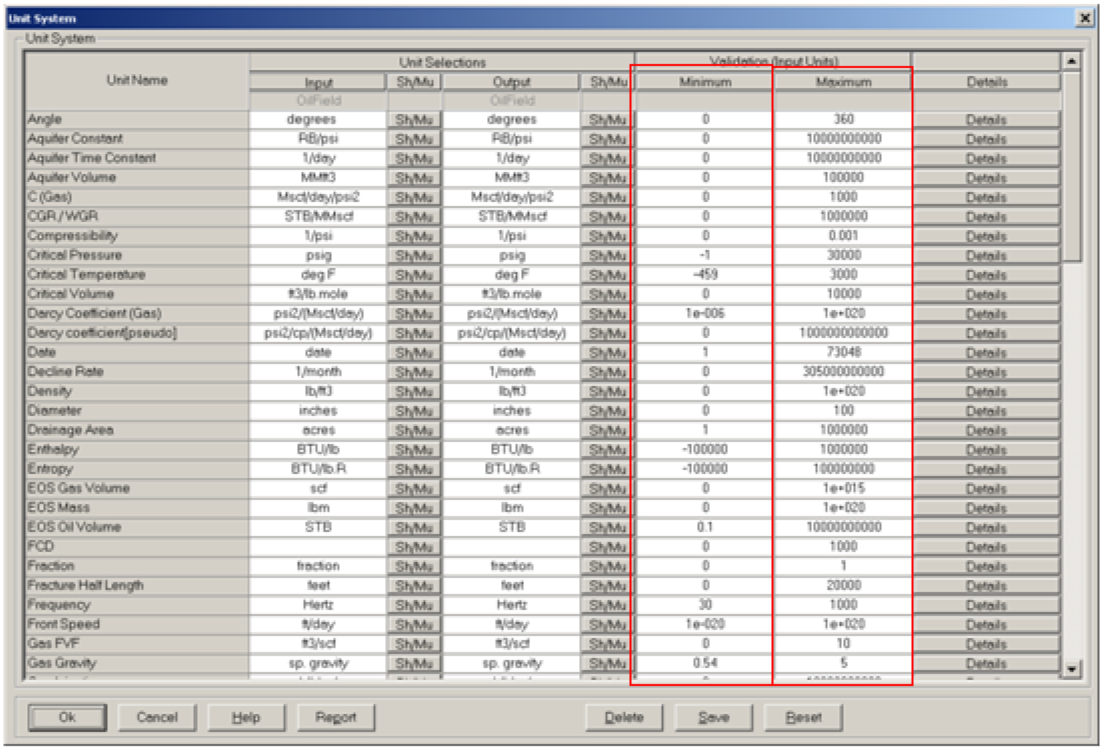
Having carried out the required changes, selecting the 'save' button will prompt the user for a name to be given to the mixed set of units.



Unit Name	Unit Selections				Validation (Input Units)		
	Input	Sh/Mu	Output	Sh/Mu	Minimum	Maximum	Deta
	OilField		OilField				
Angle	degrees	Sh/Mu	degrees	Sh/Mu	0	360	Deta
Aquifer Constant	RB/psi	Sh/Mu	RB/psi	Sh/Mu	0	10000000000	Deta
Aquifer Time Constant	1/day	Sh/Mu	1/day	Sh/Mu	0	10000000000	Deta
Aquifer Volume	MMft3	Sh/Mu	MMft3	Sh/Mu	0	100000	Deta
C (Gas)	Mscf/day/psi2	Sh/Mu	Mscf/day/psi2	Sh/Mu	0	1000	Deta
CGR / WGR	STB/MMscf	Sh/Mu	STB/MMscf	Sh/Mu	0	1000000	Deta
Compressibility	1/psi	Sh/Mu	1/psi	Sh/Mu	1e-020	0.001	Deta
Critical Pressure	psig	Sh/Mu	psig	Sh/Mu	-1	30000	Deta
Critical Temperature	deg F	Sh/Mu	deg F	Sh/Mu	-459	3000	Deta
Darcy Coefficient (Gas)	psi2/(Mscf/day)	Sh/Mu	psi2/(Mscf/day)	Sh/Mu	1e-006	1e+020	Deta
Darcy coefficient[pseudo]	psi2/cp/(Mscf/day)	Sh/Mu	psi2/cp/(Mscf/day)	Sh/Mu	0	100000000000	Deta
Date	date	Sh/Mu	date	Sh/Mu	1	73048	Deta
Decline Rate	1/month	Sh/Mu	1/month	Sh/Mu	0	305000000000	Deta
Density	lb/ft3	Sh/Mu	lb/ft3	Sh/Mu	0	1e+020	Deta
Diameter	inches	Sh/Mu	inches	Sh/Mu	0	100	Deta
Drainage Area	acres	Sh/Mu	acres	Sh/Mu	1	1000000	Deta
Enthalpy	BTU/lb	Sh/Mu	BTU/lb	Sh/Mu	-100000	1000000	Deta
Entropy	BTU/lb.R	Sh/Mu	BTU/lb.R	Sh/Mu	-100000	100000000	Deta
Fraction	fraction	Sh/Mu	fraction	Sh/Mu	0	1	Deta
Frequency	Hertz	Sh/Mu	Hertz	Sh/Mu	30	1000	Deta
Front Speed	ft/day	Sh/Mu	ft/day	Sh/Mu	1e-020	1e+020	Deta
Gas FVF	ft3/scf	Sh/Mu	ft3/scf	Sh/Mu	0	10	Deta
Gas Gravity	sp. gravity	Sh/Mu	sp. gravity	Sh/Mu	0.54	5	Deta

2.2.2.4 Minimum and Maximum Limits

When a dialogue is accessed and data entered, the program checks that each input value is within a range of values defined by a minimum and maximum value. This is to avoid obviously erroneous values being used as input to the calculations. Each measurement type has its own set of limits:



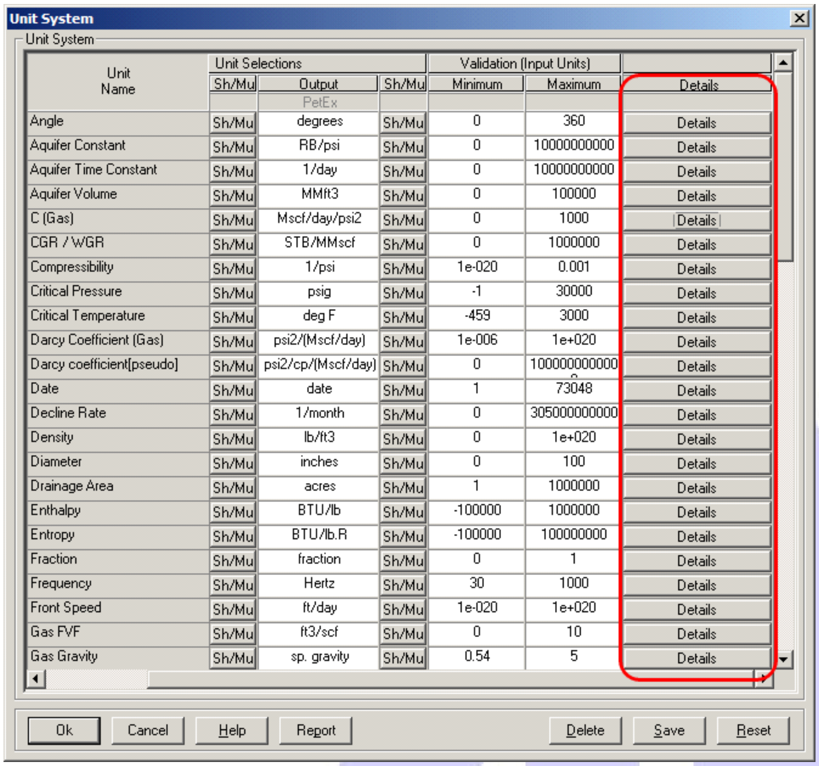
Unit Name	Unit Selections				Validation (Input Units)		
	Input	Sh/Mu	Output	Sh/Mu	Minimum	Maximum	Details
	OilField		OilField				
Angle	degrees	Sh/Mu	degrees	Sh/Mu	0	360	Details
Aquifer Constant	RB/psi	Sh/Mu	RB/psi	Sh/Mu	0	10000000000	Details
Aquifer Time Constant	1/day	Sh/Mu	1/day	Sh/Mu	0	10000000000	Details
Aquifer Volume	MMft3	Sh/Mu	MMft3	Sh/Mu	0	100000	Details
C (Gas)	Mscf/day/psi2	Sh/Mu	Mscf/day/psi2	Sh/Mu	0	1000	Details
CGR / WGR	STB/MMscf	Sh/Mu	STB/MMscf	Sh/Mu	0	1000000	Details
Compressibility	1/psi	Sh/Mu	1/psi	Sh/Mu	0	0.001	Details
Critical Pressure	psig	Sh/Mu	psig	Sh/Mu	-1	30000	Details
Critical Temperature	deg F	Sh/Mu	deg F	Sh/Mu	-459	3000	Details
Critical Volume	ft3/lb.mole	Sh/Mu	ft3/lb.mole	Sh/Mu	0	10000	Details
Darcy Coefficient (Gas)	psi2/(Mscf/day)	Sh/Mu	psi2/(Mscf/day)	Sh/Mu	1e-006	1e+020	Details
Darcy coefficient[pseudo]	psi2/cp/(Mscf/day)	Sh/Mu	psi2/cp/(Mscf/day)	Sh/Mu	0	1000000000000	Details
Date	date	Sh/Mu	date	Sh/Mu	1	73048	Details
Decline Rate	1/month	Sh/Mu	1/month	Sh/Mu	0	305000000000	Details
Density	lb/ft3	Sh/Mu	lb/ft3	Sh/Mu	0	1e+020	Details
Diameter	inches	Sh/Mu	inches	Sh/Mu	0	100	Details
Drainage Area	acres	Sh/Mu	acres	Sh/Mu	1	1000000	Details
Enthalpy	BTU/lb	Sh/Mu	BTU/lb	Sh/Mu	-100000	1000000	Details
Entropy	BTU/lb.R	Sh/Mu	BTU/lb.R	Sh/Mu	-100000	100000000	Details
EOS Gas Volume	scf	Sh/Mu	scf	Sh/Mu	0	1e+015	Details
EOS Mass	lbm	Sh/Mu	lbm	Sh/Mu	0	1e+020	Details
EOS Oil Volume	STB	Sh/Mu	STB	Sh/Mu	0.1	10000000000	Details
FCD		Sh/Mu		Sh/Mu	0	1000	Details
Fraction	fraction	Sh/Mu	fraction	Sh/Mu	0	1	Details
Fracture Half Length	feet	Sh/Mu	feet	Sh/Mu	0	20000	Details
Frequency	Hertz	Sh/Mu	Hertz	Sh/Mu	30	1000	Details
Front Speed	ft/day	Sh/Mu	ft/day	Sh/Mu	1e-020	1e+020	Details
Gas FVF	ft3/scf	Sh/Mu	ft3/scf	Sh/Mu	0	10	Details
Gas Gravity	sp. gravity	Sh/Mu	sp. gravity	Sh/Mu	0.54	5	Details

The program provides a default set of limits but the units dialogue allows changing these values. Note that the minimum and maximum fields are displayed in the current input units.

2.2.2.5 Conversion Details

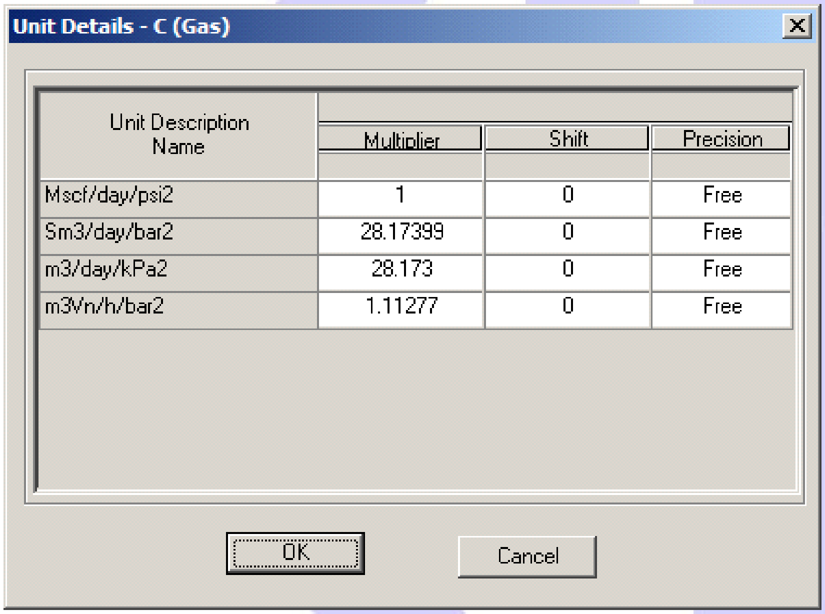
The precision for each measurement unit can also be altered. Depending on the program format settings, the precision controls how many decimal places are used when a value is displayed by the program.

Click on the details button for the measurement type that are to be changed:



Unit Name	Unit Selections			Validation (Input Units)		
	Sh/Mu	Output	Sh/Mu	Minimum	Maximum	Details
		PetEx				
Angle	Sh/Mu	degrees	Sh/Mu	0	360	Details
Aquifer Constant	Sh/Mu	RB/psi	Sh/Mu	0	10000000000	Details
Aquifer Time Constant	Sh/Mu	1/day	Sh/Mu	0	10000000000	Details
Aquifer Volume	Sh/Mu	MMft3	Sh/Mu	0	100000	Details
C (Gas)	Sh/Mu	Mscf/day/psi2	Sh/Mu	0	1000	Details
CGR / WGR	Sh/Mu	STB/MMscf	Sh/Mu	0	1000000	Details
Compressibility	Sh/Mu	1/psi	Sh/Mu	1e-020	0.001	Details
Critical Pressure	Sh/Mu	psig	Sh/Mu	-1	30000	Details
Critical Temperature	Sh/Mu	deg F	Sh/Mu	-459	3000	Details
Darcy Coefficient (Gas)	Sh/Mu	psi2/(Mscf/day)	Sh/Mu	1e-006	1e+020	Details
Darcy coefficient[pseudo]	Sh/Mu	psi2/cp/(Mscf/day)	Sh/Mu	0	100000000000	Details
Date	Sh/Mu	date	Sh/Mu	1	73048	Details
Decline Rate	Sh/Mu	1/month	Sh/Mu	0	305000000000	Details
Density	Sh/Mu	lb/ft3	Sh/Mu	0	1e+020	Details
Diameter	Sh/Mu	inches	Sh/Mu	0	100	Details
Drainage Area	Sh/Mu	acres	Sh/Mu	1	1000000	Details
Enthalpy	Sh/Mu	BTU/lb	Sh/Mu	-100000	1000000	Details
Entropy	Sh/Mu	BTU/lb.R	Sh/Mu	-100000	100000000	Details
Fraction	Sh/Mu	fraction	Sh/Mu	0	1	Details
Frequency	Sh/Mu	Hertz	Sh/Mu	30	1000	Details
Front Speed	Sh/Mu	ft/day	Sh/Mu	1e-020	1e+020	Details
Gas FVF	Sh/Mu	ft3/scf	Sh/Mu	0	10	Details
Gas Gravity	Sh/Mu	sp. gravity	Sh/Mu	0.54	5	Details

This displays a dialogue that allows alteration of the precision.



Unit Description Name	Multiplier	Shift	Precision
Mscf/day/psi2	1	0	Free
Sm3/day/bar2	28.17399	0	Free
m3/day/kPa2	28.173	0	Free
m3Vn/h/bar2	1.11277	0	Free

Please note that there is a different precision for each possible unit.

2.2.2.6 Resetting the Units

Click the 'Reset' button to reset the units to their original state (after the first installation on this PC). This will reset all unit selections, minimum/maximum values and precisions. It will also delete all user defined unit system.

2.2.2.7 Generating a Units Report

A report of the system units can be printed either directly to the printer, to an ASCII text file, or the Windows clipboard. To print a units report choose the 'Report' command. A prompt to specify the output device and appropriate format will be made available. Click 'Report' again to start the report. When printing to a file, the program prompts the user to enter a name for the report. The .TXT extension is automatically given by the program.

2.2.3 MBAL Command Buttons

The following lists the main command buttons used in **MBAL:**

Done	Returns to the previous **MBAL** dialogue box. Any changes are saved and retained in the program memory
Cancel	Returns to the **MBAL** main screen. Changes are ignored by the program
Calc	Displays a screen where calculations on the input parameters for the selected variables and correlations are performed
Save	Saves all changes made to an existing data file. By default, this command saves a file under its original name and to the drive and directory last selected
Save As	Allows a data file to be saved under a different name. A dialogue box appears prompting the user to enter a name for the new file
Report	Prints a report of the data in the relevant menu or dialogue box. • If selecting the report option from a menu, the program prompts the user to select the categories of data to print, the output device and report format. • If selecting the report command from a dialogue box, the user will be prompted for the output device and report format only
Help	Displays the **MBAL** on-line help facility. Help is also given on the keyboard and miscellaneous Windows commands
Import	Reads a data file generated by other systems containing data users would like to apply in **MBAL**. The command is user specific and available only by request
Match	Displays a variable entry screen where measured PVT laboratory data can be entered to modify the available correlations to fit the measured data.

	Only available in the PVT menu
Add	Creates a new table. **Available only with the Material Balance tool option**
Del	Deletes the table currently displayed. **Available only with the Material Balance tool option**
Plot	Displays a graphics screen where calculated results are visually displayed. • To select other axis variable, choose **Variables** • To change the plot scales, labels or colours, choose **Display** • To generate copies of a screen plot, choose **Output**
Reset	In the PVT menu this command reinstates the matched correlations to the original text book correlations. In the Material Balance tool option, this command re-initialises the regression starting values to the values last saved or to the original set of reservoir and aquifer parameters entered in the 'Reservoir Parameters' and 'Aquifer Parameters' dialogue boxes
Results	Displays a list of calculated results in the relevant menu or dialogue box. The program gives the option of printing or plotting the results displayed

2.3 Data Input and Import

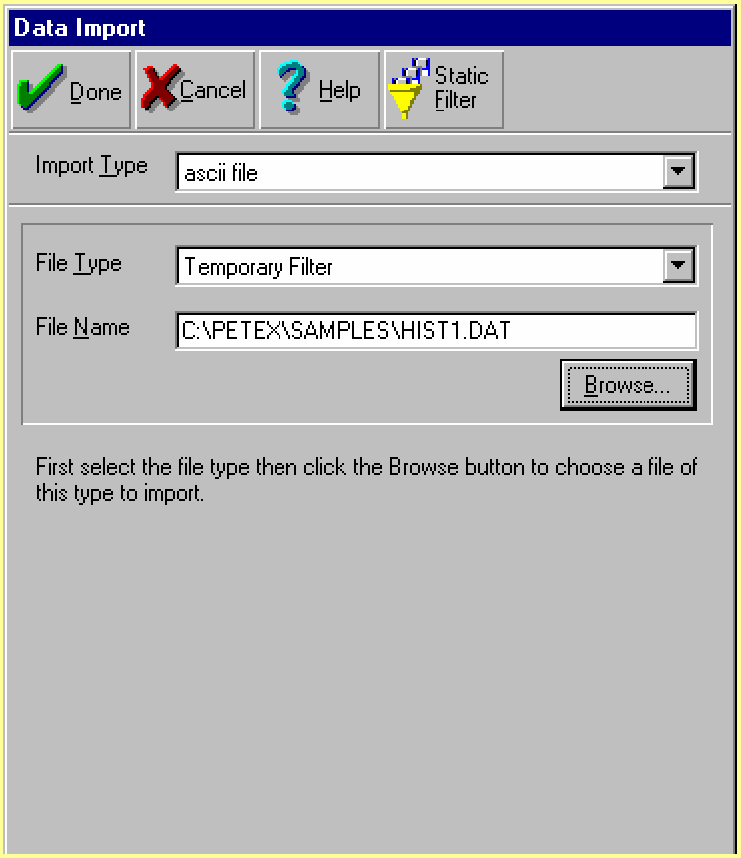
This chapter describes the **MBAL** program import facilities. These allow data to be imported into **MBAL** from external files or databases.

2.3.1 Importing Data in MBAL

This facility enables the of import tabular data from a wide variety of files and databases to be carried out. **MBAL** uses the idea of a 'filter template' for defining the format of a file or database to be imported and how the data in the import file maps to the data in **MBAL**. These filters can be configured visually and can be saved to disk for future use. They can also be distributed easily to other users.

Wherever the 'Import' button Import is available, data can be imported directly into the program tables. In some cases, the program provides the user with permanent (or hard-coded filters) such as tubing performance curves imports or imports from the binary files of other ***Petroleum Experts*** products. In most cases, user defined filters can also be created and saved to disk. These software filters can be created and used once (Temporary Filter), or they can be stored for future use (Static Filters).

Temporary filter	A temporary filter is created by using the **Temporary Filter** file type. A temporary filter can only be used once. After the data has been imported,

	the filter ‘script’ is destroyed immediately afterwards
Static filter	If a filter is built as a **Static Filter**, the ‘script’ of the filter can be stored on the disk and retrieved to be re-used or re-edited. It can also be distributed to other users of **MBAL**. Static filters are stored on disk as binary files with the MBQ extension. Once the filter has been stored it will appear automatically in the 'File Type' combo box. To create a static filter, click on the **Static Filter** and then click on **New** (see the Static Filter topic below). Warning: Static filters only appear in the 'File Type' combo box if the corresponding MBQ file has been stored in the default data directory. The data import dialogue is used to import data from the 2 sources currently supported by **MBAL**: - ASCII files - **O**pen **D**ata**b**ase **C**onnectivity sources (ODBC). Depending on the type of data being imported, only some of the data sources may be available.  Data Import Done Cancel Help Static Filter Browse... Import Type: ascii file File Type: Temporary Filter File Name: C:\PETEX\SAMPLES\HIST1.DAT First select the file type then click the Browse button to choose a file of this type to import. Once a data source has been selected using the **Import Type** combo box, the dialogue will display only the fields relevant to that data source

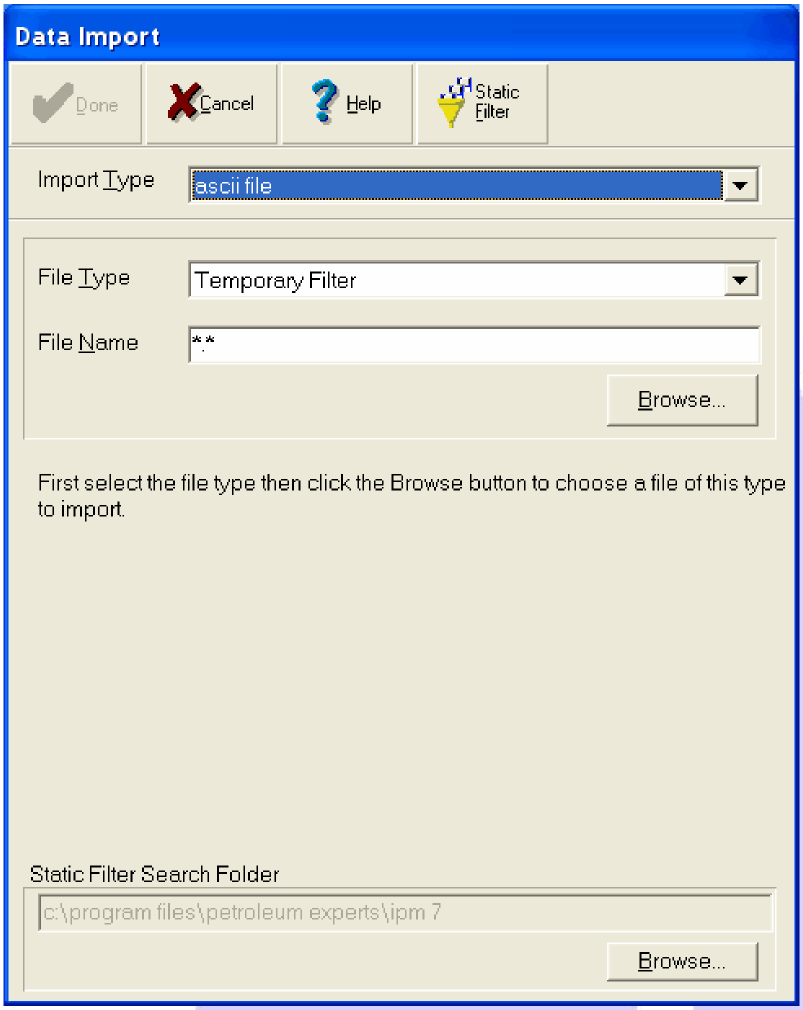
Command Buttons Data Import Dialogue

Done	Runs the selected filter and imports data into table
Static Filter	Calls the static filter dialogue. If the current 'Import Type' is ASCII file, an ASCII file filters will be displayed. If it is ODBC, then an ODBC filter will be created
ODBC	Calls the ODBC administration program, which should reside in the windows system directory if ODBC is installed on the machine in use. The program is used to set up data sources so that they may work with ODBC. *(ODBC option only)*

The following two sections describe the method of importing data from the various data sources.

2.3.1.1 Importing an ASCII File

This facility enables the import of tabular data from a wide variety of files and databases to be carried out. The hard coded filters can be selected or a static filter can be built to import the data. A filter is configured visually and can be distributed easily to other users. Each column of numbers can be modified if the correct unit does not appear in the program. Once configured, the import static filters appear on the import dialogues together with any hard coded import file types in the program.



Import Type: ascii file

File Type: Temporary Filter

File Name: *.*

First select the file type then click the Browse button to choose a file of this type to import.

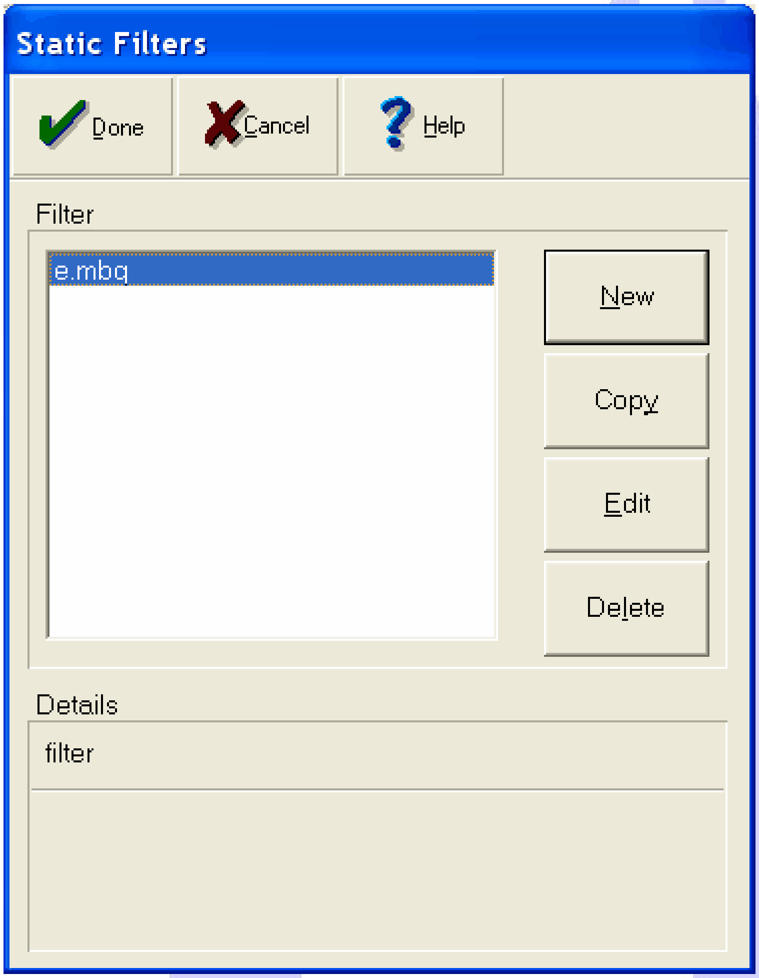
Static Filter Search Folder: c:\program files\petroleum experts\ipm 7

Input Fields for ASCII file

File Name	The full path name of the file to import may be entered in this field. When 'done' is pressed the file will be imported using the currently selected File Type. If a segment of a path is entered into this field, the dialogue will be updated to show the contents of the new directory
File Type	This combo box displays the relevant import filters. These include the hard coded filters and any static filters which have been created for this particular section of the program (i.e. filters displayed when the import dialogue is called from the PVT table will be different to those shown when the import dialogue is called from the Production History table). If the 'Temporary Filter' option is left selected, the program will create a temporary filter that is deleted once the data has been imported
Browse	Click this button to select a file from the hard disk or network drive
Static Filter	This accesses a feature that allows to create/open/edit filters

For more information on the set-up of the ASCII file import filter, see the ASCII File Import 50 section below.

2.3.1.1.1 Static Filter



e.mbq

filter

This facility is designed to allow the import of tabular data from a wide variety of files. A filter is configured visually and can be distributed easily to other users. Each column of numbers can be modified if the correct unit does not appear in the program.

Once configured the import filters appear on the import dialogues together with any hard coded import file types in the program. The following screens are only used to modify these filters.

The list box is used to select a filter whose details are then displayed at the bottom of the screen.

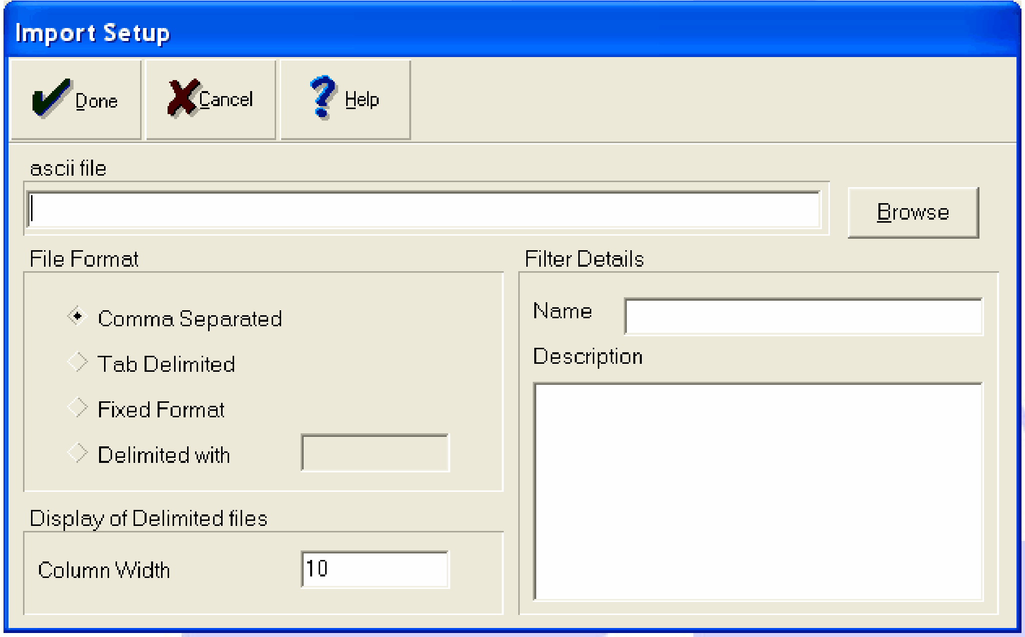
Command Buttons

New	Creates a new filter then displays the Import Setup screen

Copy	Copies the currently selected filter then displays the File Import Filter screen
Edit	Reads the currently selected filter then displays the File Import Filter screen
Delete	Deletes the currently selected filter

2.3.1.2 Import Set-up

On this screen the user can specify what type of file the filter is to accept. The delimited files are reformatted on the screen to appear as columns of a fixed length. This is done to make it easier to specify the data type and its position on each line. A file can be specified on this screen which will show the operation of the filter.



● Comma Separated
○ Tab Delimited
○ Fixed Format
○ Delimited with

Column Width 10

The steps required to import an ASCII file are defined below. They allow the relevant information to be imported while ensuring that each column of information is correctly described (i.e. the correct information is entered into the correct section in ***MBAL*** with the correct heading).

1. Browse for the relevant file containing the required information.
2. Selecting: 'Done' and 'Tab Delimited'
3. Selecting 'Done' again, the column of information should be highlighted, after which, the corresponding title for it can be selected. This would need to be carried out for all of the information presented, further detail on the definition of the data being imported is available in Import Filter 52.
4. Selecting 'Done' will then ensure that the necessary information is present in ***MBAL***.

Input Fields

ASCII File	The full path name of the example file to be used for the definition of the filter must be entered in this field
File Format	Select the format of the example file specified above. This defines how

	MBAL separates the columns of data in the example file
Name	A name for the filter type must be entered here. This will appear in the file type field of an import dialogue
Description	Up to 120 characters may be entered here to give a more comprehensive reminder of the operation of the filter. The description only appears in the bottom section of the Details field on the Import Filters dialogue
Column Width	Enter the number of characters to be displayed in each column in the next filter definition dialogue

Command Buttons

Browse	Calls up a file selection dialogue. The selected file and path is entered into the ascii file input field

2.3.1.3 Line Filter

The line filter allows to define the area of the file which contains the data to import. The check boxes may be used in together to build up complex rules. There is a hierarchy to the rules to prevent duplication.

The **First n** lines and **Last n** lines options can be used to remove sections of the file which are always of a fixed length. These two options define the area of the file within which the rest of the options work.

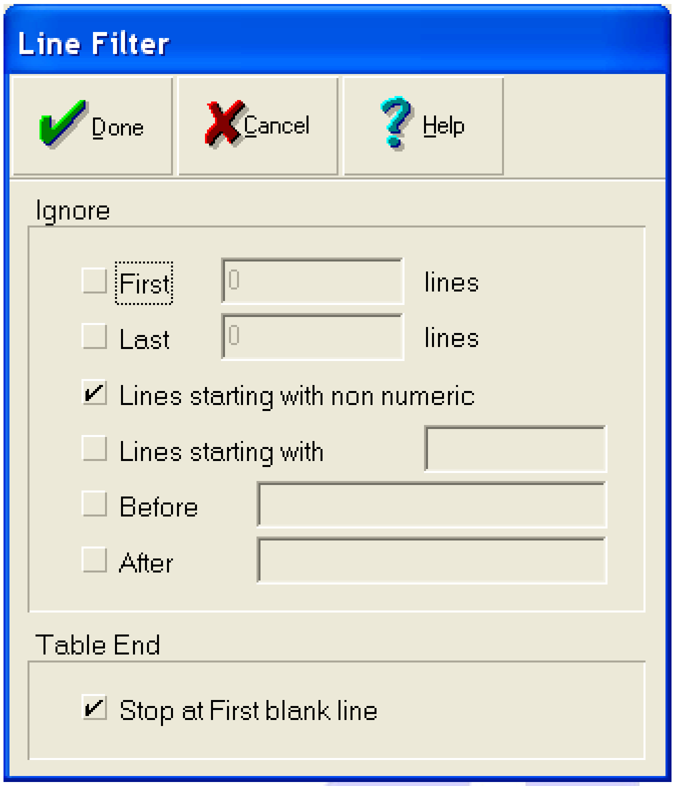
The **Before** string and **After** string can be used to ignore parts of the file which may vary in length. The string can be any pattern of characters which appear somewhere on the boundary line.

The **Table End** section only has one option, 'Stop at First Blank' line, which will cause the import filter to stop reading data from the file at the first occurrence of a blank line.

All of the options above are processed in the order in which they are described. Together they describe an area of the file in which the following options can remove further lines from the data import.

The Lines starting with **non numeric** option will ignore all lines whose first character (not including spaces) is non numeric.

The Lines starting with **string** option allows the user to enter a pattern (up to .. characters) which will then exclude lines from the import



Ignore

☐ First 0 lines

☐ Last 0 lines

☑ Lines starting with non numeric

☐ Lines starting with

☐ Before

☐ After

Table End

☑ Stop at First blank line

Input Fields

All of these fields are only available if the option is checked.

First n lines	Enter the number of lines, starting from the top of the file, to be ignored
Last n lines	Enter the number of lines, starting from the bottom of the file, to be ignored
Lines starting	Enter the pattern which occurs at the start of lines to be ignored
Before	Enter the pattern which occurs somewhere in the last line which is to be ignored (from the start of the file)
After	Enter the pattern which occurs somewhere in the first line to be ignored (after reading has started)

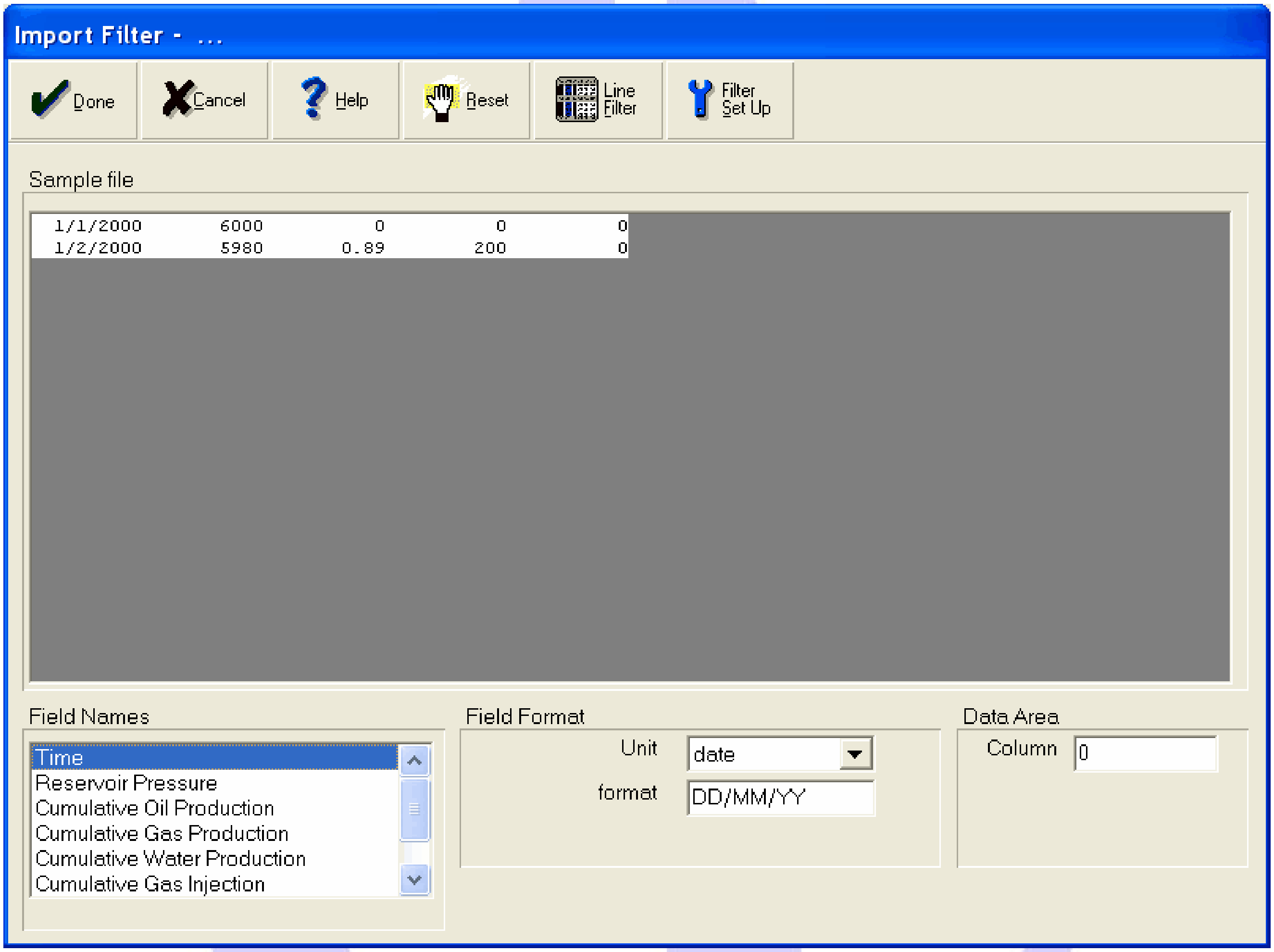
2.3.1.4 Import Filter

On this page, how the required information for **MBAL** is to be read can be defined how the filter reads each line from the file. A text window displays the ASCII file or database, which is completely greyed except for the data area the first time this screen is displayed. From this screen, data can be matched with the variable names and the data units can be set.

If a new filter is being defined, the 'Import Filter' dialogue needs to be called up to define the data area. Having done this, columns of data for each field in the list box can be selected. Once defined, this column will be blue. If the selection in the 'Field Names' list box changes the column will turn red.

In the 'Field Format' area, the units of the data in the import file can be set. The 'Shift' and 'Multiplier' fields can be used to modify the data before it is converted into the units set for the program.

The graphical selections are echoed into the files in the 'Data Area' section. Alternatively the column number of line section may be entered here.


Import Filter - ...
Done
Cancel
Help
Reset
Line Filter
Filter Set Up
Sample file
Field Names
Field Format
Data Area

```
  1/1/2000        6000           0           0           0
  1/2/2000        5980        0.89         200           0
```

Field Names:

- Time
- Reservoir Pressure
- Cumulative Oil Production
- Cumulative Gas Production
- Cumulative Water Production
- Cumulative Gas Injection

Unit: date

format: DD/MM/YY

Column: 0

Input Fields

Unit	A combo box can be used to list the units defined for the measurement in the **MBAL** program

If the measurement is of time and the unit is date:

Format	A date format can be entered here using the characters Y, M & D separated by an “/”. If the date in this field is to be the ‘end of the month’ any number greater than 30 can be entered. If the data in the file contains no delimiters the format defines the number of characters read as the day, month & year. For example: data: 8901 format : YYMM result is January 1989 data: 8901 format : YYM result in an error data: 8901 format : MYY results is August 1990 data: 89/01 format : M/Y results is January 1989 ➲ **MBAL** picks up the default date format from the Windows *Internatic*

Otherwise:

Multiplier	The data read from the file is multiplied by this number
Shift	This number is added to the product of the Multiplier and the data read from the file
If less than	This field can be used to handle entries below this value in a special way. If the 'carry over radio' button is set, the last valid value read is copied to this entry in the table. When the 'ignore radio' button is set the value will be set to a blank in the table

If the file type is delimited:

Column	Enter the column of numbers displayed on the screen which contains the data. Any valid graphical selection will be echoed in this field

If the file type is fixed format:

Start	Enter the column in which the data starts
End	Enter the column in which the data ends

These fields will echo any valid graphical selection and must contain the longest number in the column of data.

Command Buttons:

Reset	Prompts the user to confirm the resetting of the data in the filter.
Filter	Displays the Import Filter dialogue.
Set-up	Displays the Import Set-up dialogue.
Done	When the user is defining a new filter a file selection dialogue is displayed for

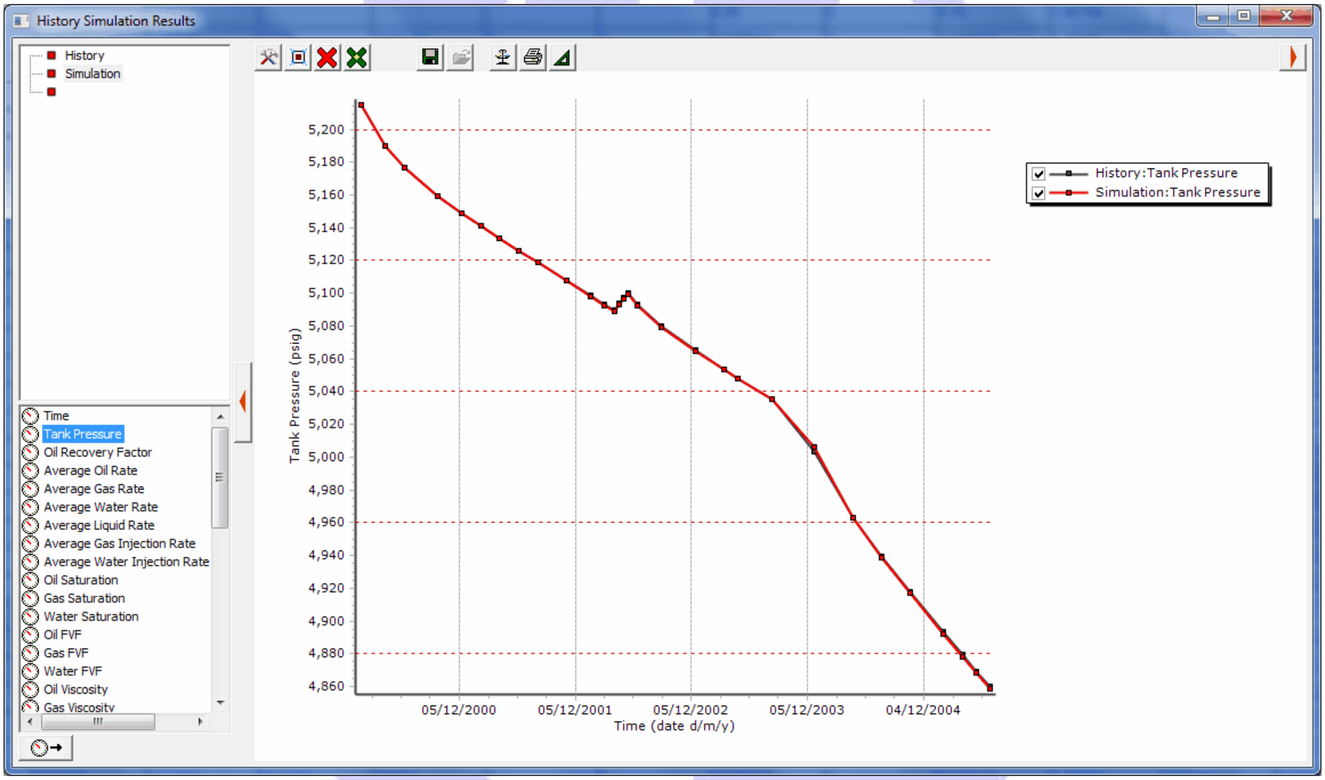
	the file name to be entered. If an existing filter is being edited, it will be saved automatically when this button is pressed.

2.3.1.5 Plots, Reports

This chapter describes the **MBAL** program plot and report facilities. It explains how to modify a plot, change plot colours and print a plot display. This chapter also describes the report dialogue box and explains how to set up a report and export it.

2.3.1.5.1 The Plot Screen

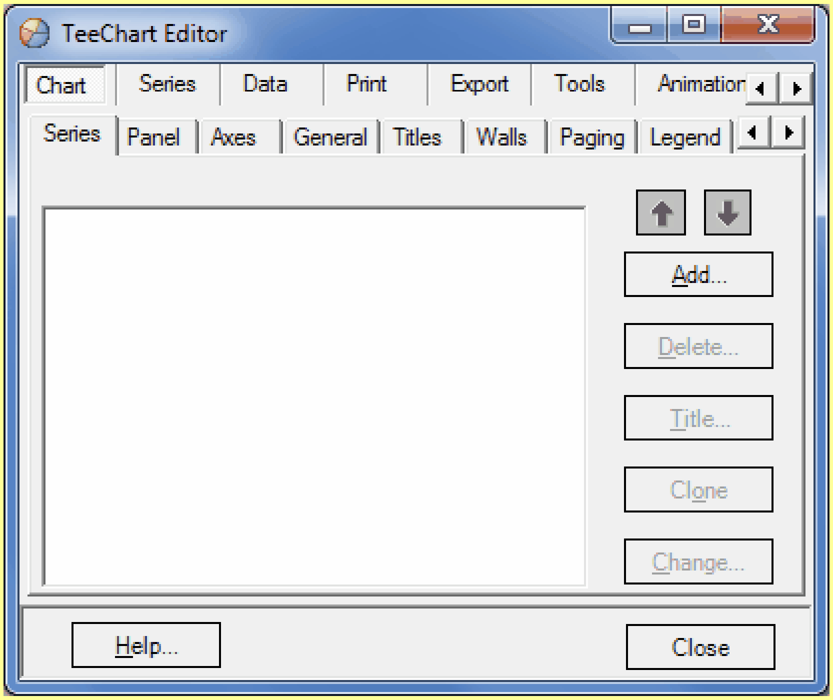
Plot screens can be accessed directly through the relevant dialogue box using the **Plot** command button. Where data has been saved, the program also presents the facility of accessing a plot through the relevant menu.
Throughout **MBAL**, the menu command, or command button to access a graphic display will always be **Plot**. Selecting this option calls up the 'Tee' chart. A screen similar to the following appears:

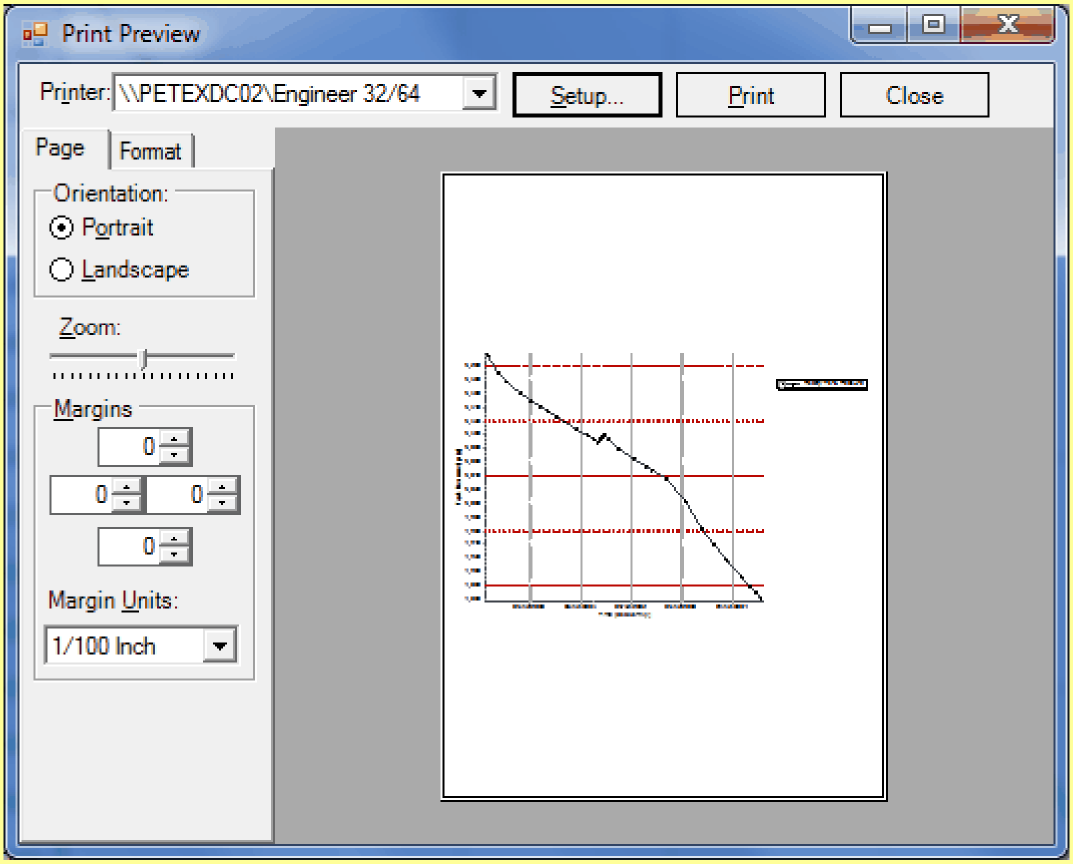

History Simulation Results
History
Simulation
Time
Tank Pressure
Oil Recovery Factor
Average Oil Rate
Average Gas Rate
Average Water Rate
Average Liquid Rate
Average Gas Injection Rate
Average Water Injection Rate
Oil Saturation
Gas Saturation
Water Saturation
Oil FVF
Gas FVF
Water FVF
Oil Viscosity
Gas Viscosity
5,200
5,180
5,160
5,140
5,120
5,100
5,080
5,060
5,040
5,020
5,000
4,980
4,960
4,940
4,920
4,900
4,880
4,860
Tank Pressure (psig)
05/12/2000
05/12/2001
05/12/2002
05/12/2003
04/12/2004
Time (date d/m/y)
History:Tank Pressure
Simulation:Tank Pressure

The upper left hand section can be used to retrieve various history or simulated results (including saved results) for plotting. The variables to be plotted can be selected from the lower left hand section. Note that to save a result stream, this has to be done from the calculations results interface.

A useful feature to plot multiple variables for different groups of results is by using the ⏲→ button. When a set of results is selected from above left section and a variable is selected from the lower left section, clicking on this button will allow to plot the same variable for the sets/ groups of results.

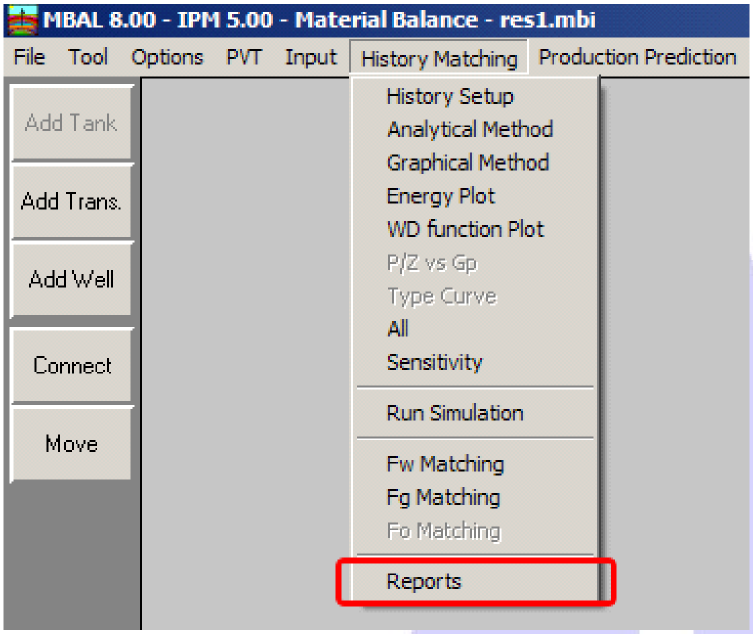
To change a plot display, use any of the following menu options on the plot menu bar.

🛠	Tee-chart editor for new Tee chart plotting feature in MBAL. The editor can be used to edit the plot display including axis, legend, data set, scales, colours etc.  TeeChart Editor Chart Series Data Print Export Tools Animation Series Panel Axes General Titles Walls Paging Legend Add... Delete... Title... Clone Change... Help... Close
⊡	Cancels any zoom and redraws the original plot
❌	Removes a single series from the plot through a selection interface
✖	Removes multiple series from the plot through a selection screen
💾	Use this option to save a plotting configuration which can be recalled for use later.
📂	Use this option to retrieve a saved plotting configuration
⊥	Quick access option to edit scales, legend and labels
🖨	Use to print a hardcopy of the plot(s). Selecting this option brings up the interface below where the various printers configured to the computer can be selected from. Other options include being able to select an orientation or setup paper size etc.

	 Print Preview Setup... Print Close Page Format Zoom: Margins Printer: \\PETEXDC02\Engineer 32/64 Orientation: ● Portrait ○ Landscape Margins: 0 0 0 0 Margin Units: 1/100 Inch
◢	Quick access option to edit line widths and symbol sizes

2.3.1.5.2 Reporting

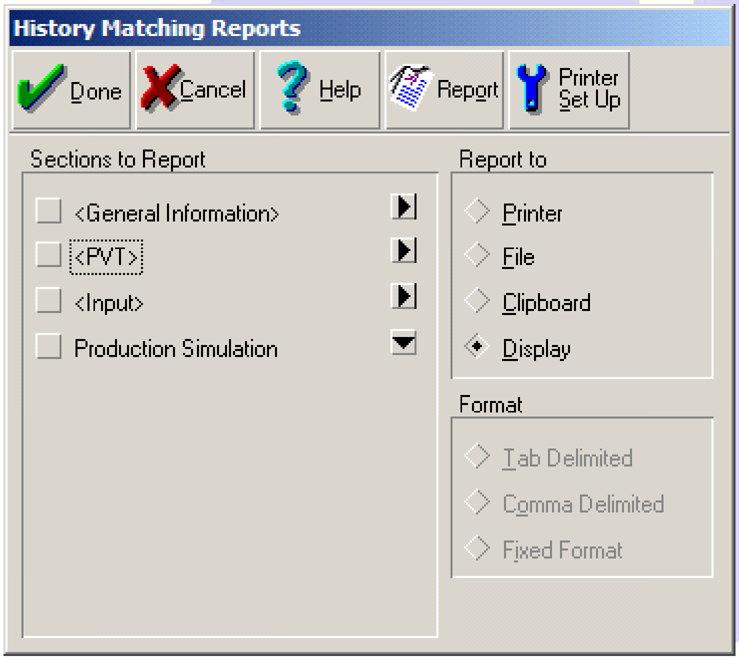
This section describes the options relevant for printing or viewing a report. All of the main menu items in **MBAL** have a reporting option with default report options ready for commercial reports:


MBAL 8.00 - IPM 5.00 - Material Balance - res1.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
Add Tank
Add Trans.
Add Well
Connect
Move
History Setup
Analytical Method
Graphical Method
Energy Plot
WD function Plot
P/Z vs Gp
Type Curve
All
Sensitivity
Run Simulation
Fw Matching
Fg Matching
Fo Matching
Reports

The PVT, Input and Production Prediction options have similar reporting options that work on the same principles as described below:

2.3.1.5.2.1 Selecting sections to include in the report

Selecting the “Reports” option shown above will display the following screen:


History Matching Reports
Done
Cancel
Help
Report
Printer Set Up
Sections to Report
☐ <General Information>
☐ <PVT>
☐ <Input>
☐ Production Simulation
Report to
○ Printer
○ File
○ Clipboard
● Display
Format
○ Tab Delimited
○ Comma Delimited
○ Fixed Format

Prior to printing a report, we recommend that the data file be saved. In the unlikely event of a printer error or some other unforeseen problem, this simple procedure could prevent any work from being lost.

Report to

Select the output device:

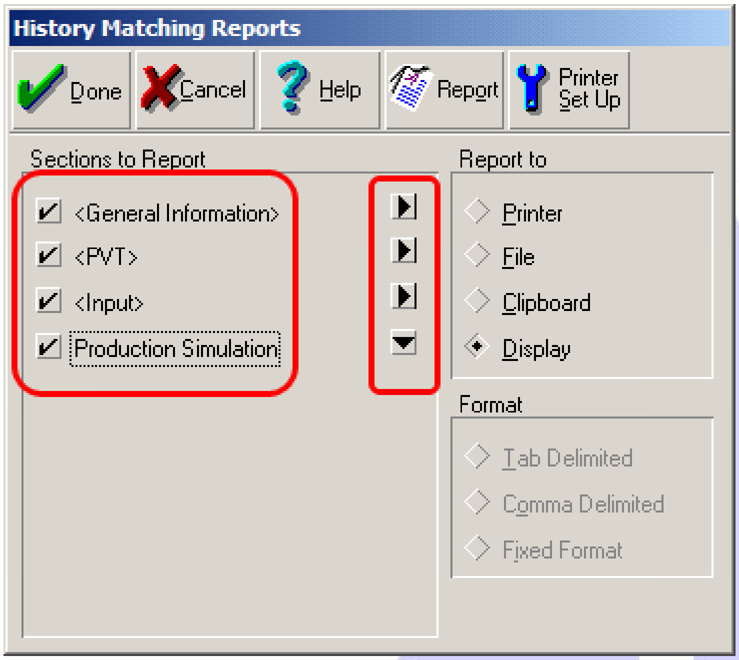
Printer	Sends the results directly to the attached printer in the format and layout specified in the Printer setup.
File	Generates an ASCII text file (*.PRN) that can be imported into any word processing or spreadsheet program (e.g. Windows Write, MS Excel). A dialogue box appears promoting the user to name the report. The extension is automatically given by the program
Clipboard	Sends a copy to the Windows clipboard, where the user can view or copy the data into any word processing or spreadsheet program. The contents of the clipboard deleted and replaced whenever new data is copied to the clipboard. If a report is desired from the clipboard, start the preferred Windows word processing or spreadsheet program and open a new document. Next, select the program's Edit menu and choose the Paste command
Display	Invokes the Windows notepad facility, in which results can be viewed or edited prior to printing

Format

Next select the report format: (available for **File** and **Clipboard** options only).

Fixed format	Delimits the data columns with blank spaces. This format is fine for viewing data
Comma delimited	Spaces the data columns with commas
Tab delimited	Spaces the data columns with tabulation markers which allows easy creation of tables or format data. Use this format when exporting reports to word processing or spreadsheet programs

The information available for reporting is displayed in the sections menu and the user can then select which of these to include in the report. For example, if all the information is required, first select all of the options by clicking on the boxes next to them:


History Matching Reports
Done
Cancel
Help
Report
Printer Set Up

Sections to Report

☑ <General Information>
☑ <PVT>
☑ <Input>
☑ Production Simulation

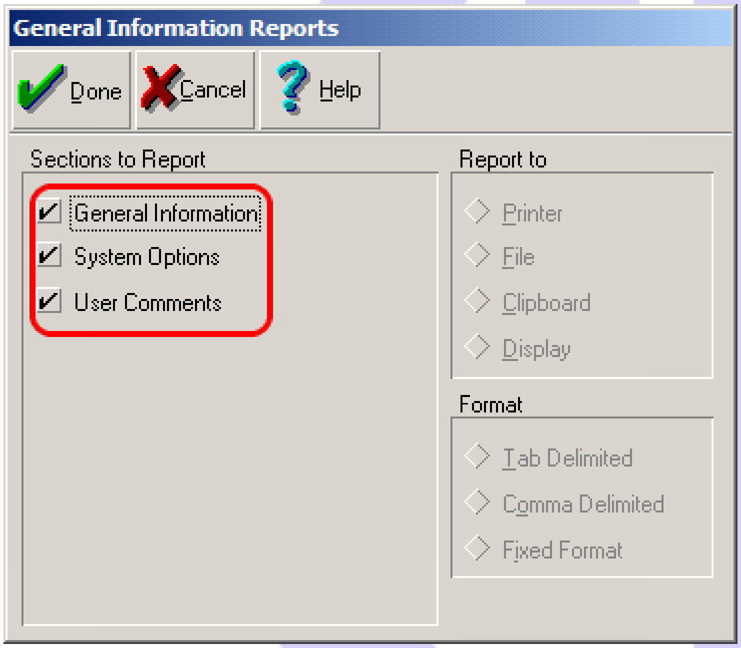
Report to

○ Printer
○ File
○ Clipboard
● Display

Format

○ Tab Delimited
○ Comma Delimited
○ Fixed Format

Then the information relevant to each option can be selected by clicking on the extend buttons shown above:


General Information Reports
Done
Cancel
Help

Sections to Report

☑ General Information
☑ System Options
☑ User Comments

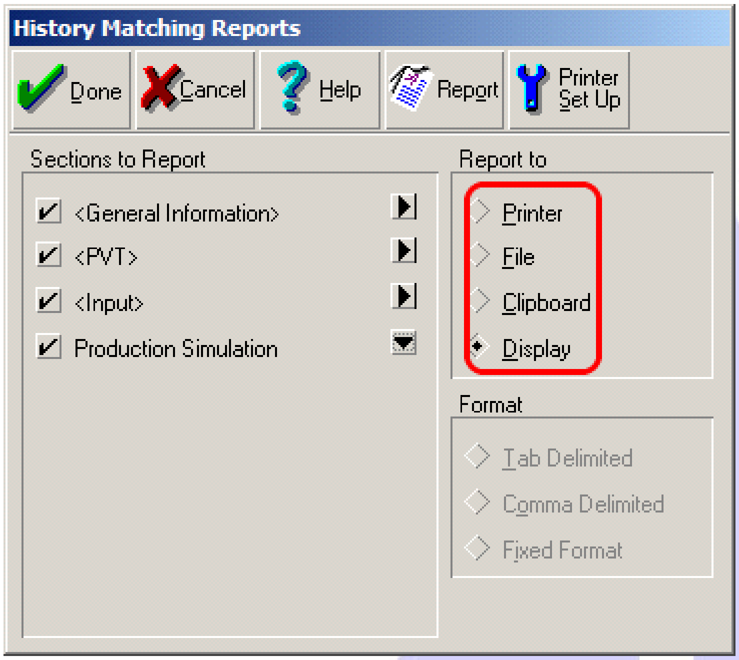
Report to

○ Printer
○ File
○ Clipboard
○ Display

Format

○ Tab Delimited
○ Comma Delimited
○ Fixed Format

As soon as these options are chosen, then the output method can be selected from the main report screen:



Sections to Report

☑ <General Information>

☑ <PVT>

☑ <Input>

☑ Production Simulation

Report to

○ Printer

○ File

○ Clipboard

● Display

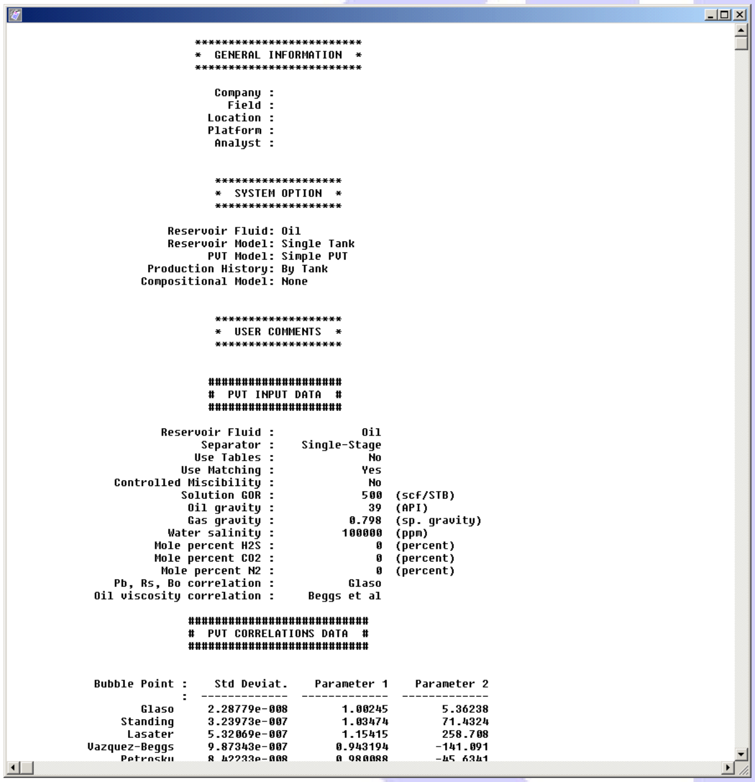
Format

○ Tab Delimited

○ Comma Delimited

○ Fixed Format

Clicking the “Report” button now will create the report in the relevant format:



```
                  *************************
                  *  GENERAL INFORMATION  *
                  *************************

                     Company :
                       Field :
                    Location :
                    Platform :
                     Analyst :


                     ******************
                     *  SYSTEM OPTION  *
                     ******************

              Reservoir Fluid: Oil
              Reservoir Model: Single Tank
                    PVT Model: Simple PVT
           Production History: By Tank
          Compositional Model: None


                     ******************
                     *  USER COMMENTS  *
                     ******************


                    ####################
                    #  PVT INPUT DATA  #
                    ####################

             Reservoir Fluid :            Oil
                   Separator :   Single-Stage
                  Use Tables :             No
                Use Matching :            Yes
     Controlled Miscibility :             No
                Solution GOR :            500  (scf/STB)
                 Oil gravity :             39  (API)
                 Gas gravity :          0.798  (sp. gravity)
              Water salinity :         100000  (ppm)
           Mole percent H2S :              0  (percent)
           Mole percent CO2 :              0  (percent)
            Mole percent N2 :              0  (percent)
     Pb, Rs, Bo correlation :          Glaso
  Oil viscosity correlation :     Beggs et al

                 ###########################
                 #  PVT CORRELATIONS DATA  #
                 ###########################


  Bubble Point :    Std Deviat.    Parameter 1    Parameter 2
               :  -------------  -------------  -------------
         Glaso    2.28779e-008        1.00245        5.36238
      Standing    3.23973e-007        1.03474        71.4324
       Lasater    5.32069e-007        1.15415        258.708
 Vazquez-Beggs    9.87343e-007       0.943194       -141.091
      Petrosky    8.42233e-008       0.980088       -45.6341
```

2.3.1.5.2.2 Solving printing problems

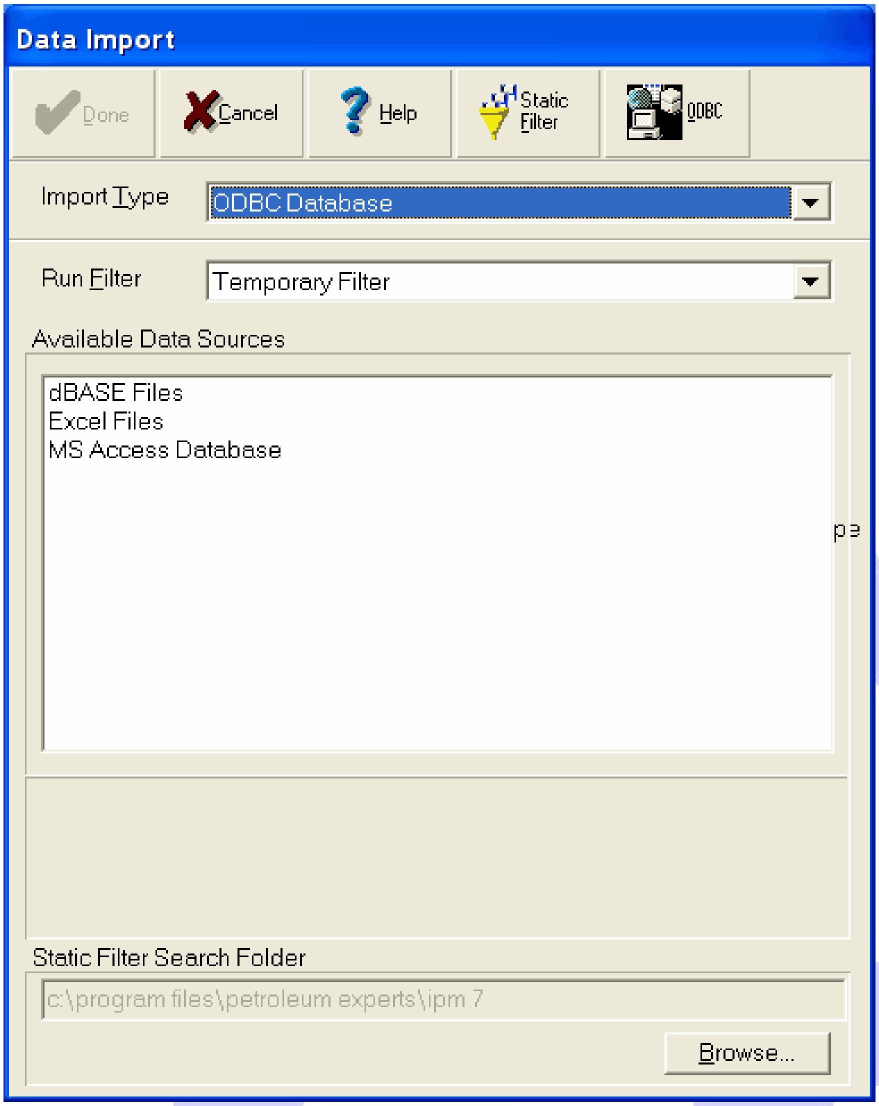
If the printed output does not look like the format seen on the screen, the following can be checked:

- Ensure that sufficient space to create a printer file is available on disk.
- Ensure that the printer is connected properly, it is ON and on-line.
- Ensure that the correct printer and port from the Printer Set Up have been selected. If the printer file cannot be read, it could then be verified that the appropriate printer port has been selected (usually 'LPT1').
- Ensure that the correct fonts and printer fonts for the driver were installed. When Windows cannot find the appropriate font, it will automatically carry out a substitution for another font.
- Check that the latest version of the printer driver has been installed. If an old printer driver is in use, the document may not print or will compress to form an unreadable file

2.3.1.6 Importing data from an ODBC Datasource

This feature has been designed around the Open Data Base Connectivity standard to present the user with a common interface to a wide variety of data sources. The ODBC drivers which currently exist can support such diverse sources as dBase files and Oracle 7. At present, data can be imported from 1 table at a time and supported with additional SQL to filter the data set.

ODBC is an addition to the operating system (i.e. WinXP, NT 4.0) and as such is not supplied by Petroleum Experts Ltd.



Import Type: ODBC Database

Run Filter: Temporary Filter

Available Data Sources

dBASE Files
Excel Files
MS Access Database

Static Filter Search Folder: c:\program files\petroleum experts\ipm 7

Input Fields for ODBC Database

Run Filter	This combo box shows the import filters which are relevant. The filters run by this tool are similar to queries run on a database. If **temporary filter** is selected, a temporary filter is created, however, after the information has been imported it will automatically be deleted. When a filter, other than **Temporary**, has been selected a data source from the list box cannot be selected
Available Data Sources	This list box can be used to select any of the databases which have been set up with ODBC tools on the computer. Once selected, a temporary filter to import the data can be built. This filter is destroyed after it has been run. To save a filter, click the static filter button to set up a permanent filter

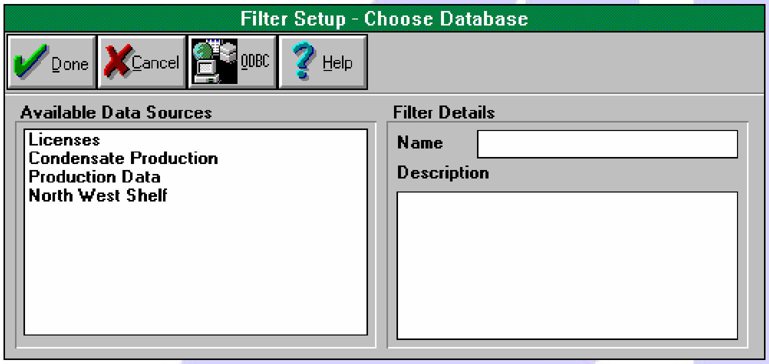
Command Buttons

Done	If the Temporary Filter has been selected then this calls the ODBC Database Import - Filter Setup dialogue. Otherwise it calls the ODBC Table &Field Selection dialogue
ODBC	Calls the ODBC administrator program - this is part of the operating system rather than a Petroleum Experts product

.

2.3.1.6.1 Filter Set-up

The ODBC filter operates in the same manner as the ASCII filter described in Import Filter with the exception of the 2 dialogues used to define the data set.
This dialogue is used to select the data source on which the filter is to be based. When building a static filter it is required to enter a name for the filter which will appear in the Run Filter combo box of the Data Import dialogue.



Licenses
Condensate Production
Production Data
North West Shelf

Input Fields

Name	A name for the filter type can be entered here. This will appear in the file type field of an import dialogue
Description	Up to 120 characters may be entered here to give a more comprehensive reminder of the operation of the filter. The description only appears in the bottom section of the Details field on the Import Filters dialogue
Available Data Sources	Data sources which have been configured to communicate with ODBC

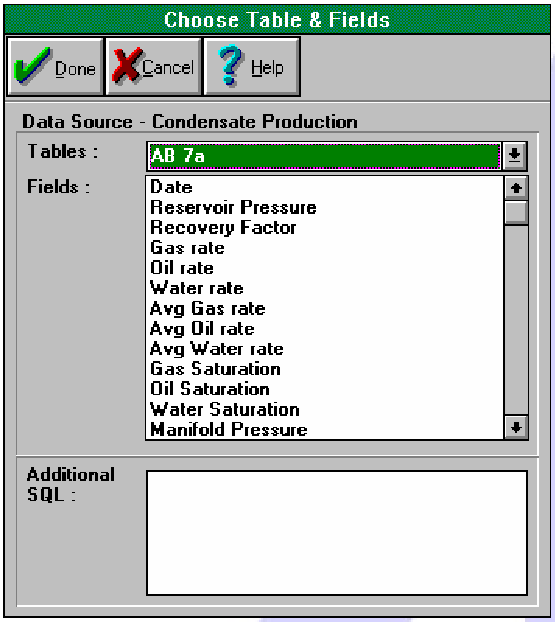
Command Buttons:

Done	Calls the Table/Fields dialogue

ODBC	Calls the ODBC administrator program

2.3.1.7 Choose Table & Fields

Once a data source has been chosen the table and fields to be included in the filter can be selected. Data can be imported from one table at a time with the current system.



Data Source - Condensate Production

Tables : AB 7a

Fields :
Date
Reservoir Pressure
Recovery Factor
Gas rate
Oil rate
Water rate
Avg Gas rate
Avg Oil rate
Avg Water rate
Gas Saturation
Oil Saturation
Water Saturation
Manifold Pressure

Additional SQL :

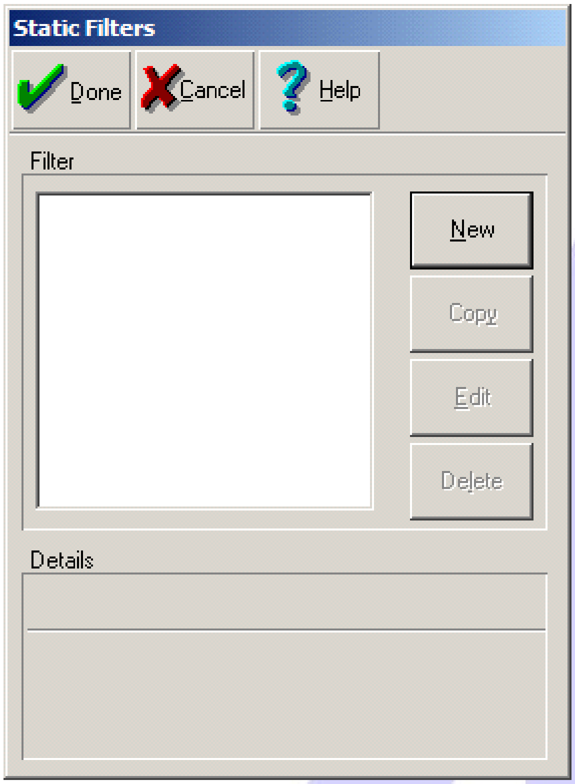
Input Fields

Tables	Select the required table from which data is to be retrieved
Fields	Select the fields that containing the data which is to be imported
Additional SQL	Additional **S**tructured **Q**uery **L**anguage can be entered here to filter the data set. This section is designed for use with one shot filters (i.e. Temporary) and is not saved in the static filter file

2.3.2 Static Import Filter

This feature allows the building of filters which can be re-used or even distributed to other users of the program. Any filters that are built as static filters will be listed on the data import dialogue. If it is an ASCII filter it will be in the list of filter types, and if it is for an ODBC data source it will appear in the list of filters to run. The temporary filter option displayed in these lists is a static filter which is run once, then destroyed.

Static filters are administered with the Static Filter dialogue shown below. This dialogue will list the filters for the current import type, i.e. if it is 'ASCII File' only files which contain ASCII filters will be listed. Consequently when the New, Copy or Edit buttons are clicked, the options relevant to the import type are presented.



This screen is accessed by the **Static Filter** button on the file import dialogues which appear throughout the program. It is from here that the import filters can be managed.

The list box is used to select a filter, the details of which are then displayed at the bottom of the screen.

Command Buttons:

New	Creates a new filter then displays the Import Set-up screen
Copy	Copies the currently selected filter then displays the File Import Filter screen
Edit	Reads the currently selected filter then displays the File Import Filter screen
Delete	Deletes the currently selected filter

2.3.3 Defining the system

This chapter describes the program **Tool** and **Options** menus.

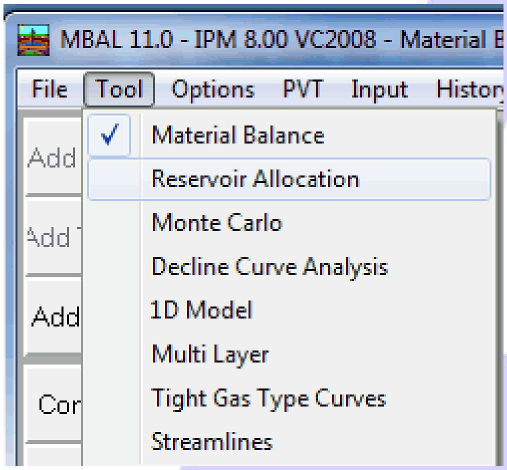
The selections made in these screens set the scope of the **MBAL** program. They establish the inputs required and specify the nature of the calculations that will be performed. The parameters selected are global for the current active file.

On selecting the analysis tool, the options on the menu bar will change with respect to the tool in use. This is due to **MBAL**'s *smart data input feature*. The options displayed will correspond to the analysis tool selected and are different between the tools. This smart menu feature simplifies the process of data entry by displaying only those options; fields and input parameters, relevant to the chosen application.

The tool selection can be changed at any time. It should be noted however, that new choices may require more or different data to be supplied and in some cases recalculated.

2.3.3.1 Reservoir Analysis Tools

The function of the **Tool** menu is to define the reservoir engineering analysis tool. The menu lists the current reservoir engineering tools available in **MBAL**.


MBAL 11.0 - IPM 8.00 VC2008 - Material B
File
Tool
Options
PVT
Input
Histor
✓ Material Balance
Reservoir Allocation
Monte Carlo
Decline Curve Analysis
1D Model
Multi Layer
Tight Gas Type Curves
Streamlines
Add
Add
Add
Cor

To access this menu, click the menu name or press **ALT T**. The following analytical tools are displayed:

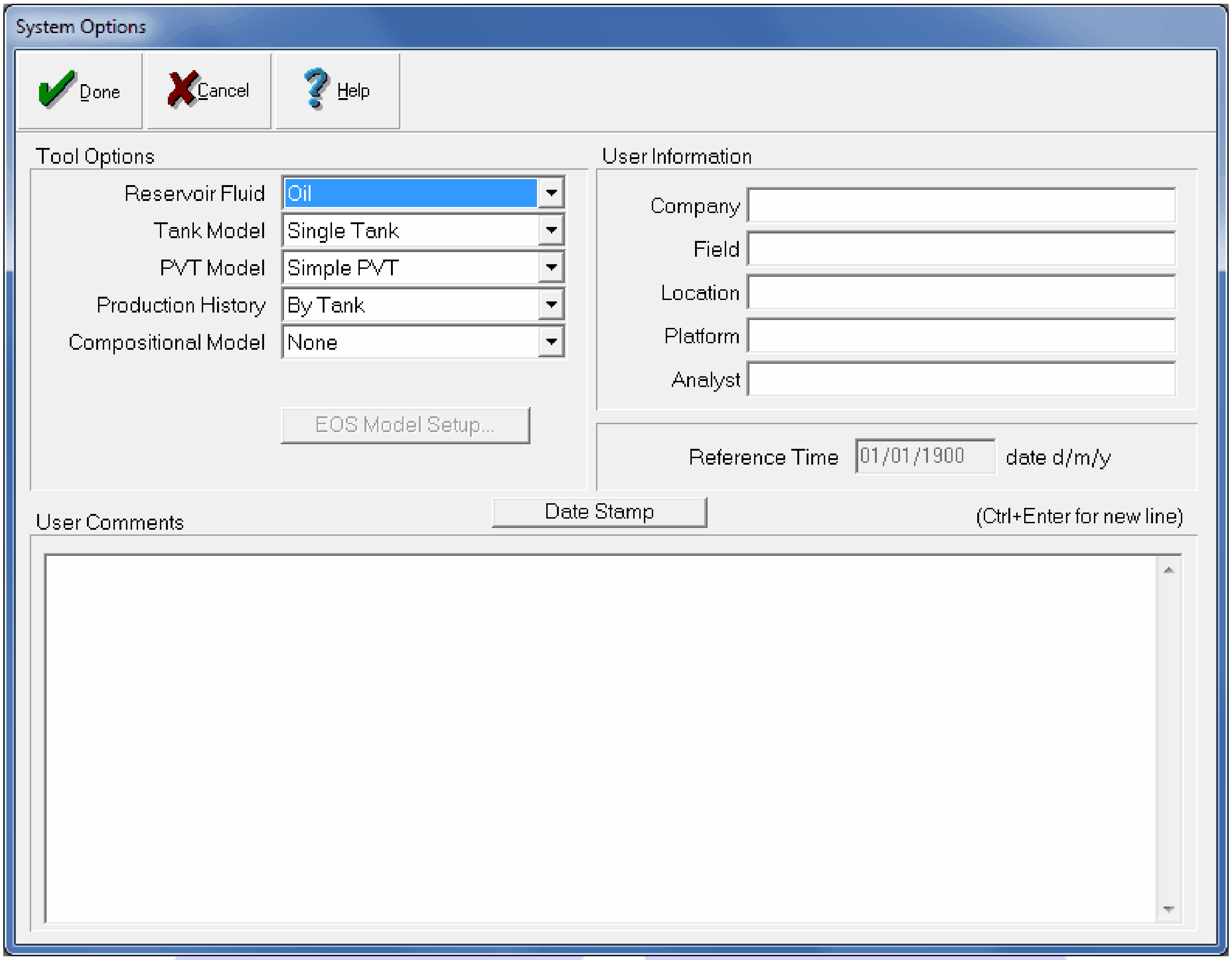
Material Balance	This model enables the user to perform the classical history matching to determine fluid originally in place as well as aquifer influx. Predictions can also be made using relative permeabilities and well performances (IPR, VLP) to evaluate future reservoir performance based on different production strategies. The material balance models can also be used in **GAP** for full system modelling and optimisation
Reservoir Allocation	This tool back-allocates reserves in a multilayer system if only cumulative production per well is known. It takes into account the IPR of each layer as well as the rate of depletion and is an improvement to the classical kh technique
Monte Carlo Statistical	Statistical tool for estimating oil and gas in place

Modelling	
Decline Curve Analysis	This is the classical decline curve analysis tool whereby production history is fitted to curves that are then extrapolated in an attempt to predict future performance
1D Model	Analysis of water flooding in an oil reservoir (Buckley-Leverett analysis) and ability to evaluate simple EOR type studies for one dimensional flow
Multi Layer	Calculation of average pseudo-relative permeabilities for a multi-layer reservoir
Multi Layer	This tool is designed to model low perm gas reservoirs and coalbed methane plays
Tight Gas Type Curves	This tool provides with methodologies to analyse, history match and use a model for tight gas reservoirs, which are by definition transient
Streamlines	A simple 2-D reservoir tool to evaluate sweep efficiencies and producer fractional flows

2.3.3.2 System options

Once the analysis tool has been selected, the **Options** menu can be invoked.

To access the **Options** menu, click the menu name or press **ALT O**. A dialogue, as seen below will appear:


System Options
Done
Cancel
Help
Tool Options
User Information
Company
Field
Location
Platform
Analyst
EOS Model Setup...
User Comments
Date Stamp
(Ctrl+Enter for new line)

Reservoir Fluid: Oil
Tank Model: Single Tank
PVT Model: Simple PVT
Production History: By Tank
Compositional Model: None
Reference Time: 01/01/1900 date d/m/y

This dialogue box has three main sections:

Tool Options	Where the different options available for the tool selected in the **Tool** menu can be chosen
User Information	These fields may be used to identify the reservoir and analyst working on the model. The information entered here will appear on the report and screen plots
User Comments	This is a space where a log of the updates/changes to the file can be kept

2.3.3.2.1 Tool options

To select an option, click the arrow to the right of the field to display the current choices. To move to the next entry field, click the field to highlight the entry, or use the **TAB** button. The options displayed are determined by the analysis tool selected in the **Tool** menu. For more information on these fields refer to the relevant analysis tool chapter.

2.3.3.2.2 User information

The information for these fields is optional. The details entered here provide the banner/header information that identifies the reservoir in the reports and plots generated by the program.

2.3.3.2.3 User comments and date stamp

This box is used to keep a history log of events on the system or modifications made to the file since it was started. An unlimited amount of text is allowed. Press **Ctrl+Enter** to start a new paragraph. The comments window can be viewed by either dragging the scroll bar thumb or using the and directional arrow keys. The **Date Stamp** command adds the current date and time to the user comments box.

2.3.4 Describing the PVT

In order to accurately predict both pressure and saturation changes throughout the reservoir, it is important that the properties of the fluid are accurately described. The ideal situation would be to have data from laboratory studies carried out on fluid samples. As this is not always possible, **MBAL** offers several options for calculating the required fluid properties:

Correlations	Where only basic PVT data is available, the program uses traditional black oil correlations, such as Glaso, Beal, and Petrosky etc. A unique black oil model is available for condensates and details of this can be found later in this guide as well as the ***PROSPER*** manual
Matching	Where both basic fluid data and some PVT laboratory measurements are available, the program can modify the black oil correlations to best-fit the measured data using a non-linear regression technique
Tables	Where detailed PVT laboratory data is provided, **MBAL** uses this data instead of the calculated properties. This data is entered in table format (PVT tables), and can be supplied either manually or imported from an outside source. So called black oil tables can be generated from an EOS model and then be imported and used in **MBAL.** **NOTE:** **Tables are usually generated using one fluid composition which implies a single GOR for the fluid. This will therefore not provide the right fluid description when we have injection of hydrocarbons in the reservoir or when the reservoir pressure drops below the bubble/dew point**
Compositional	Where the full Equation of State description of the fluid is available and all the PVT can be obtained from a Peng-Robinson or an SRK description of the fluid phase behaviour **NOTE:** **The basic equations of state are not predictive unless matched to**

	measured lab data. Care has to be taken in order to make sure that the EOS has been matched and is applicable for the range of pressures and temperatures to be investigated

The following summarises the steps to take based on the amount of PVT information available to the user.

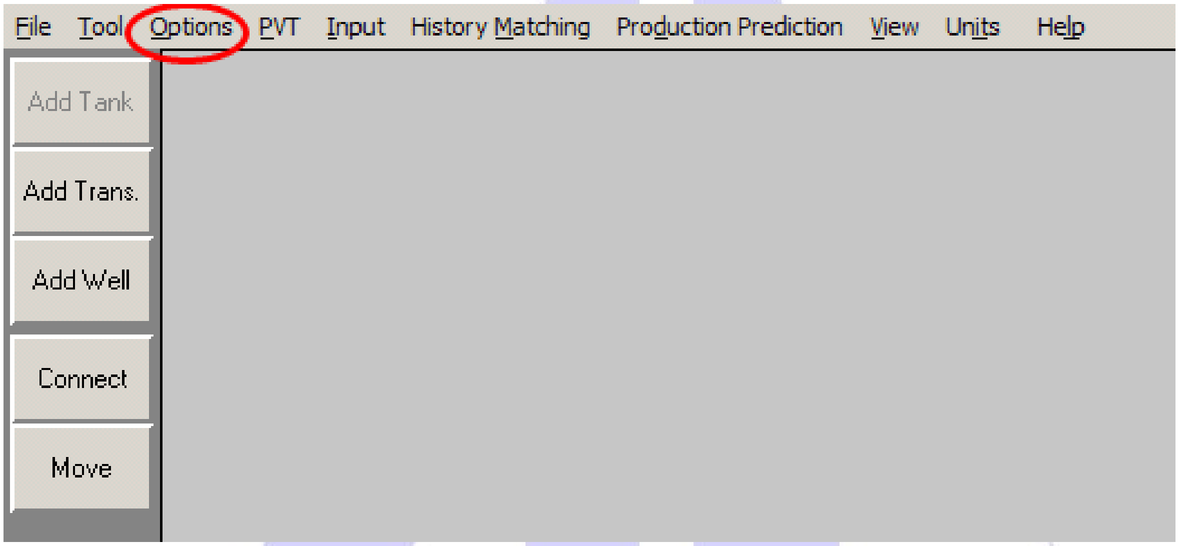
Using PVT correlations	Choose PVT | Fluid Properties, and enter the data requested in the input dialogue box. Select the correlation known to best fit the fluid type
Using PVT matching	Where additional PVT laboratory data is available, these can be used to adjust the PVT correlations following the steps: • Choose the 'Match' command to enter the PVT laboratory data. The measured data and fluid data entered in the 'Fluid Properties' screen must be consistent. Flash data must be used. The bubble point should be entered in the match table for each temperature as well. • Choose the 'Match' command to adjust the selected correlation with the PVT measured data. Check the parameters and match correlations. • Choose 'Calc' to start the non-linear regression that will modify the correlations. • Choose 'Results' to view the matching parameters. Identify the correlation with the lowest correction (parameter 1) and standard deviation, and use this correlation in all further calculations of fluid property data
Using PVT tables	• Choose PVT | Fluid Properties, and enter the data required in the input dialogue box. Select the correlation known to best fit the fluid type. • Choose the 'Tables' command to use the PVT tables. Up to 5 input tables for different temperatures are allowed. Enter the data manually, or choose the Import command to import the PVT data from an external source. Ensure the 'Use Tables' option is checked in the PVT data input dialogue
Checking the PVT calculations	To determine the quality of the PVT calculations, return to the 'Fluid Properties' dialogue box. and click 'Calc'. Enter a range of pressures and temperatures for the calculation. The ranges defined should cover the range of pressures expected. The calculations performed can be: • Automatic: where fluid properties are calculated for a specific range and number of steps, or • User defined: where fluid property values are calculated for specific pressure and temperature points Choose **Calc**, to return to the calculations screen. The previous calculation results are displayed. Choose **Calc** again to start a new calculation. When

	the calculations have finished click **Plot** to view the calculated and measured results

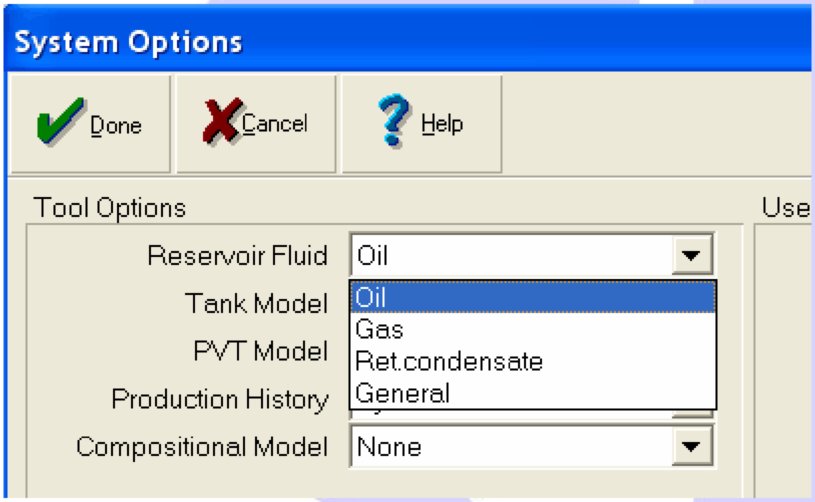
2.3.4.1 Selecting the PVT method

The following paragraphs summarise the steps to be taken based on the amount of PVT information available.

Under the system 'Options':


File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Add Tank
Add Trans.
Add Well
Connect
Move

Here the fluid can be selected, as well as the method with respect to compositional modelling.


System Options
Done
Cancel
Help
Tool Options
Use
Oil
Gas
Ret.condensate
General

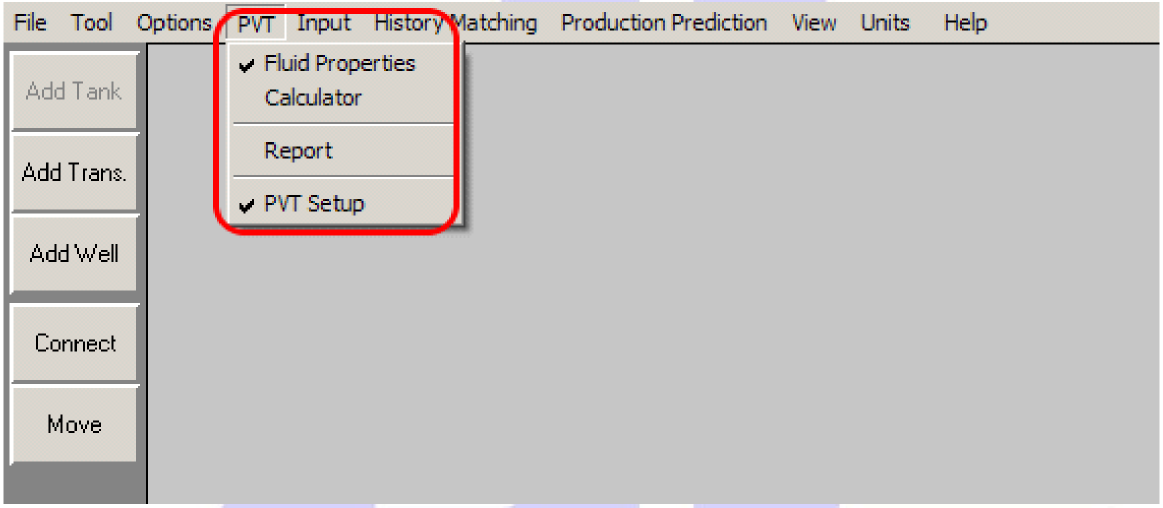
Reservoir Fluid: Oil
Tank Model
PVT Model
Production History
Compositional Model: None

Oil	This option uses oil as the primary fluid in the reservoir. Any gas cap properties will be treated as dry gas
Gas ***(Dry and***	Wet gas is handled under the assumption that all liquid condensation occurs at the separator. The liquid is put back into the gas as an equivalent gas quantity. The pressure drop is therefore calculated on the basis of a single

Wet Gas)	phase gas, unless water is present
Retrograde Condensate	**MBAL** uses the retrograde condensate Black Oil model. These models take into account liquid dropout in the reservoir at different pressures and temperatures
General	This option allows a tank to be treated as an oil leg with a gas cap containing a condensate rather than dry gas. In other words, a tank can be treated as an oil tank with an initial condensate gas cap or as a condensate tank with an initial oil leg. This means that the user can enter a full black oil description of the oil (as would be done for the old oil case) and a full black oil description for the gas condensate (as would be done for the old retrograde condensate case). This allows modelling of solution gas bubbling out of the oil in the tank, as well as liquid drop out in the tank from the gas. The user may still choose to only enter one model i.e. oil or condensate. This will give compatibility with old **MBAL** files. If we have a full oil and gas model, we can calculate oil properties above the dew point and gas properties above the bubble point. This allows modelling of super-critical fluids. We still need to define a tank to either be predominately oil or condensate. There are two main reasons: • It is convenient to define a tank fluid type from a display point of view. The tank type controls how we input the fluid in place i.e. OOIP and gas cap fraction or OGIP and oil leg fraction. It also defines the predominant fluid in the history matching e.g. gas or oil graphical plots. However these should not affect the results (apart from that mentioned below). We should get the same results if we analyze as an oil tank with a gas cap or a condensate tank with an oil leg. • The tank type defines the wetting phase. This may have an effect on the calculation of the maximum saturation of the oil or gas phase. For example, the maximum gas saturation is 1.0-Swc for a condensate tank but is 1.0-Sro-Swc for an oil tank. This may effect the calculations of the relative permeabilities. If the fluid type is changed from an oil to a condensate tank, **MBAL** will automatically recalculate the input fluid volumes and pore volume vs. depth tables assuming that there is both initial oil and gas. Whether the tank is defined as oil or condensate, both oil and gas wells can be defined for a tank. Suitable relative permeabilities can be used to allow production only from an oil leg or from the gas cap. Another feature of this method is the full tracking of gas injection in the tank. The main benefit is that production of injected gas can now be controlled by use of recirculation breakthroughs. Previously, gas production always contained a mixture of original gas and injected gas based on a volumetric

	average. Thus as soon as gas injection started, the produced CGR would start to drop. If no breakthroughs are entered, this will still be the case. However we are now able to enter a recirculation breakthrough. Whilst the gas injection saturation is below this breakthrough, none of the injection gas will be recirculated. This will mean that injection gas will remain in the tank. The user may also enter a gas injection saturation at which full recirculation takes place. At this saturation, only injected gas is produced. Between the breakthrough and full recirculation saturation, a linear interpolation of the two boundary conditions is used

Once the relevant options are selected, then the PVT screen can be accessed:



This will allow entry of the relevant data to describe the fluid behaviour. The following sections will describe the PVT definition and validation procedures depending on the fluid to be modelled.

This chapter will be split into two main sections, one with respect to the black oil options and one referring to the compositional options.

2.3.4.2 Black Oil PVT Descriptions

In this section, all of the options with respect to the black oil model for PVT descriptions will be described. The definition “Black Oil” means that the fluid will be treated as two phases, oil and gas. It can also be applied to condensate reservoirs.

In **MBAL** there is a unique condensate model that can describe the properties of retrograde condensate fluids but needs to be validated first. This validation will also be explained.

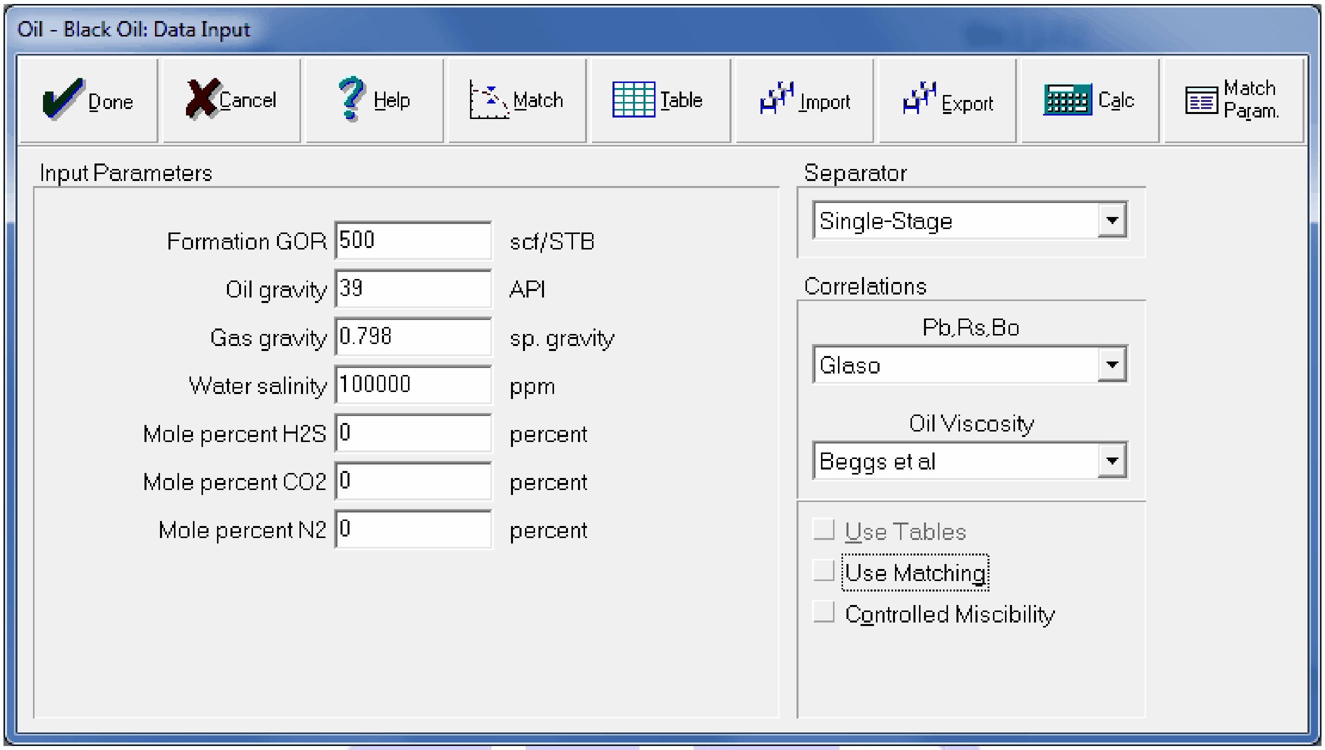
2.3.4.2.1 PVT Command buttons

The following command buttons are common to all the black oil PVT input screens:

Calc	Displays a calculation screen where the calculations on the input parameters for the selected correlations are performed
Import	This option is used with the 'Tables' command, and is open to users who would like to bring in their PVT data from an outside source. This option is user specific an available only by special request
Match	Displays a variable entry screen in which PVT laboratory data can be entered to modify the available correlations to fit the measured data
Next	In the 'Match Data' or 'Tables' screens, this command displays the next PVT input table
Plot	Displays a graphics screen where calculated results are visually displayed. • To select other axis variables, choose the 'Variables' command. • To change the plot scales, labels or colours, choose the 'Display' command. • To generate copies of a selected screen plot, choose the 'Output' command
Reset	Used in the 'Match Data' calculation screen, the 'Reset' command reinstates the matched correlations to the original text book correlations
Table	Displays a variable entry screen where detailed PVT laboratory data can be entered or imported. This command works with the 'Use Tables' flag. When the option is checked, the program uses the measured data provided in the tables. If the program requires data that is not provided in the tables, it will calculate the data using the selected correlation

2.3.4.2.2 PVT for Oil

If oil has been defined as the fluid type in the **Options** menu, the following PVT dialogue box is displayed:



Input Parameters

Formation GOR 500 scf/STB
Oil gravity 39 API
Gas gravity 0.798 sp. gravity
Water salinity 100000 ppm
Mole percent H2S 0 percent
Mole percent CO2 0 percent
Mole percent N2 0 percent

Separator
Single-Stage

Correlations
Pb,Rs,Bo: Glaso
Oil Viscosity: Beggs et al

☐ Use Tables
☐ Use Matching
☐ Controlled Miscibility

Enter the required fluid data in the fields provided:

Input Parameters

Formation GOR	This is the solution GOR at the bubble point and should not include any free gas production. The solution GOR is given by flashing the oil at the bubble point to standard conditions and determining the ratio of the volume of gas and volume of oil obtained, both expressed at standard conditions
Oil Gravity	This is the gravity of the condensate obtained by flashing the total fluid to standard conditions. The gravity is defined as the ratio of the condensate density to the water density, both at standard conditions
Gas gravity	This is defined as the ratio of the density of the gas to the density of the air both at standard conditions, equal to the ratio of the gas molecular weight to the air molecular weight
Water salinity	Concentration of salts in water expressed in ppm equivalent
Mole % of **CO2, N2 and H2S**	These represent the molar percent of the impurities in the gas stream separated at standard conditions

Input Fields

Separator	Select the format of the data to enter, either single stage or two-stage separation train to standard conditions
Correlations	Select the gas viscosity correlation to apply
Use Tables	Check the 'Use Tables' flag if the program is to use the measured PVT data supplied in the PVT tables. In parameters where detailed PVT data is provided, MBAL will use these values instead of the correlations. Disallow (uncheck) this option, if it is decided to use the (matched or un-matched) black oil correlations instead of the PVT tables. This button will be disabled if no table data has been entered - click the 'Table' button to enter the table data
Use Matching	Check the 'Use Matching' box if it is desired to use the matched black oil correlations. Disallow (uncheck) this option, if it is decided to use the original unmatched black oil correlations. This button will be disabled if no matching data has been calculated - click the Matching button to enter matching data and calculate matching parameters
Controlled Miscibility	This option is used to control how free gas redissolves into the oil if the pressure of the fluid increases

Multiple PVT Definitions (fpor further reading please see the variable PVT section 98)

In some circumstances, the PVT section will allow the user to define more than one set of PVT data. Note that each set of PVT data includes the input PVT (e.g. GOR, API, gas gravity) as well as matching tables, matching parameters and table data. In these cases the above dialogues will look slightly different:

- All of the currently defined sets of PVT data will be listed down the right hand side of the dialogue. Click on the PVT definition which is to be edited - all of the fields and the actions relating to the buttons will now act on the PVT definition selected.
- An extra field will be displayed at the top of the dialogue to allowing the name of the PVT definition to be altered.
- Three buttons are also displayed at the top of the dialogue. Click on the plus button to create a new empty PVT definition. Click on the minus button to delete the currently selected PVT definition. Click on the multiply button to create a new PVT definition which is a copy of the currently selected PVT definition.

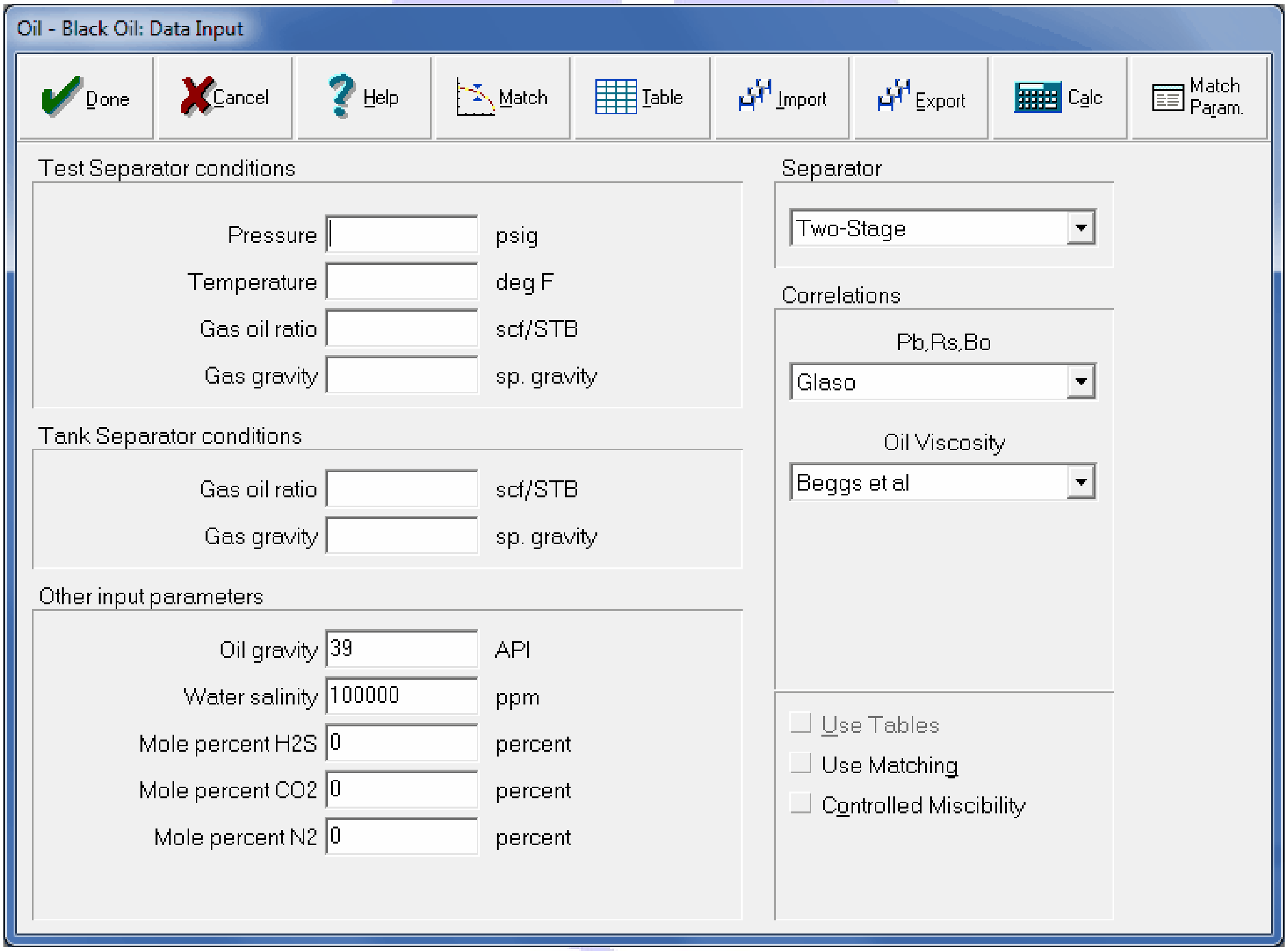
Command Buttons

Match	Displays a variable entry dialogue box in which measured PVT laboratory data can be entered to modify the selected correlations so that they fit the measured data
Table	Displays a variable entry screen in which the user can enter or import detailed PVT laboratory data. This command works with the 'Use Tables'

	flag. When the option is checked, the program uses the measured data provided in the tables. If **MBAL** requires data not provided in the tables, it will calculate the necessary parameters using the selected correlation
Import	Displays a dialogue to allow selection of a **PROSPER** PVT file to import into **MBAL**
Calc	Displays a dialogue box where calculations on PVT parameters are performed using the current PVT model. This can be used to verify the consistency of the PVT data entered
Match Param	Displays a dialogue to view or edit the current matching parameters

2.3.4.2.2.1 Two stage separator

This screen appears if oil is defined as the reservoir fluid type in the **Options** menu and the two stage separator has been selected in the ***Separator*** control.



Test Separator conditions
Pressure psig
Temperature deg F
Gas oil ratio scf/STB
Gas gravity sp. gravity

Tank Separator conditions
Gas oil ratio scf/STB
Gas gravity sp. gravity

Other input parameters
Oil gravity 39 API
Water salinity 100000 ppm
Mole percent H2S 0 percent
Mole percent CO2 0 percent
Mole percent N2 0 percent

Separator: Two-Stage

Correlations
Pb,Rs,Bo: Glaso
Oil Viscosity: Beggs et al

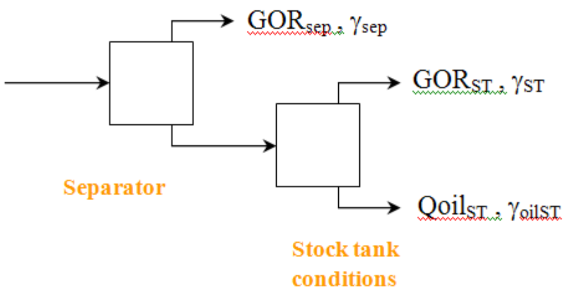
☐ Use Tables
☐ Use Matching
☐ Controlled Miscibility

Enter the required fluid data in the fields provided.

Input Parameters

These are the basic input data required by the black oil model in form of gas gravity, oil gravity and GOR (or CGR), which are determined by flashing the fluid down to standard conditions through separator train. This train defines the "path" to standard conditions used to express the standard volumes (rates).

The meaning of the PVT input properties for a black oil model is illustrated in the following figure and in the comments below:


GOR_{sep}, γ_{sep}
GOR_{ST}, γ_{ST}
$Qoil_{ST}$, γ_{oilST}
Separator
Stock tank conditions

Where:

γ_i = specific gas gravities

γ_{oilST} = oil gravity

GOR_i=(Volume of gas @ STD at stage i) / $Qoil_{ST}$

Total GOR: $GOR_{tot} = GOR_{sep} + GOR_{ST}$

The average specific gravity is given by:

$$\gamma_g = \sum_i \frac{GOR_i \cdot \gamma_i}{GOR_{tot}} = \frac{GOR_{sep} \cdot \gamma_{sep} + GOR_{ST} \cdot \gamma_{ST}}{GOR_{tot}}$$

The oil gravity is by definition the ratio between the density of the oil and the water both at STD.

The impurities correspond to the mole % of CO2, N2 and H2S in the gas liberated in the process shown above.

The formula above can be used to reduce a train of 'n' separators to an equivalent one stage.

GOR	This is the ratio of the volume of gas liberated at each stage to the volume of oil at the last stage (both expressed as volumes at standard conditions) obtained by flashing the total fluid to standard conditions through the separator train above
Oil Gravity	This is the gravity of the condensate obtained by flashing the total

	fluid to standard conditions. The gravity is defined as ratio of the condensate density to the water density, both at standard conditions
Gas gravity	This is defined as the ratio of the density of the gas to the density of the air both at standard conditions, equal to the ratio of the gas molecular weight to the air molecular weight
Water salinity	Concentration of salts in water expressed in ppm equivalent
Mole % of **CO2, N2 and H2S**	These represent the molar percent of the impurities in the gas stream separated at standard conditions

Input Fields

Separator	Select the format of the data to enter, either single stage or two-stage separation train to standard conditions
Correlations	Select the gas viscosity correlation to apply
Use Tables	Check the 'Use Tables' flag if the program is to use the measured PVT data supplied in the PVT tables. In parameters where detailed PVT data is provided, MBAL will use these values instead of the correlations. Disallow (uncheck) this option, if it is decided to use the (matched or un-matched) black oil correlations instead of the PVT tables. This button will be disabled if no table data has been entered - click the 'Table' button to enter the table data
Use Matching	The 'Use Matching' box will be checked if it is desired to use the matched black oil correlations. Disallow (uncheck) this option, if it is decided to use the original unmatched black oil correlations. This button will be disabled if no matching data has been calculated - click the Matching button to enter matching data and calculate matching parameters
Controlled Miscibility	This option is used to control how free gas redissolves into the oil if the pressure of the fluid increases

Multiple PVT Definitions

In some circumstances, the PVT section will allow the user to define more than one set of PVT data. Note that each set of PVT data includes the input PVT (e.g. GOR, API, gas gravity) as well as matching tables, matching parameters and table data. In these cases the above dialogues will look slightly different:

- All of the currently defined sets of PVT data will be listed down the right hand side of the dialogue. Click on the PVT definition which is to be edited - all of the fields and the actions relating to the buttons will now act on the PVT definition selected.
- An extra field will be displayed at the top of the dialogue to allowing the name of the PVT definition to be altered.

- Three buttons are also displayed at the top of the dialogue. Click on the plus button to create a new empty PVT definition. Click on the minus button to delete the currently selected PVT definition. Click on the multiply button to create a new PVT definition which is a copy of the currently selected PVT definition.

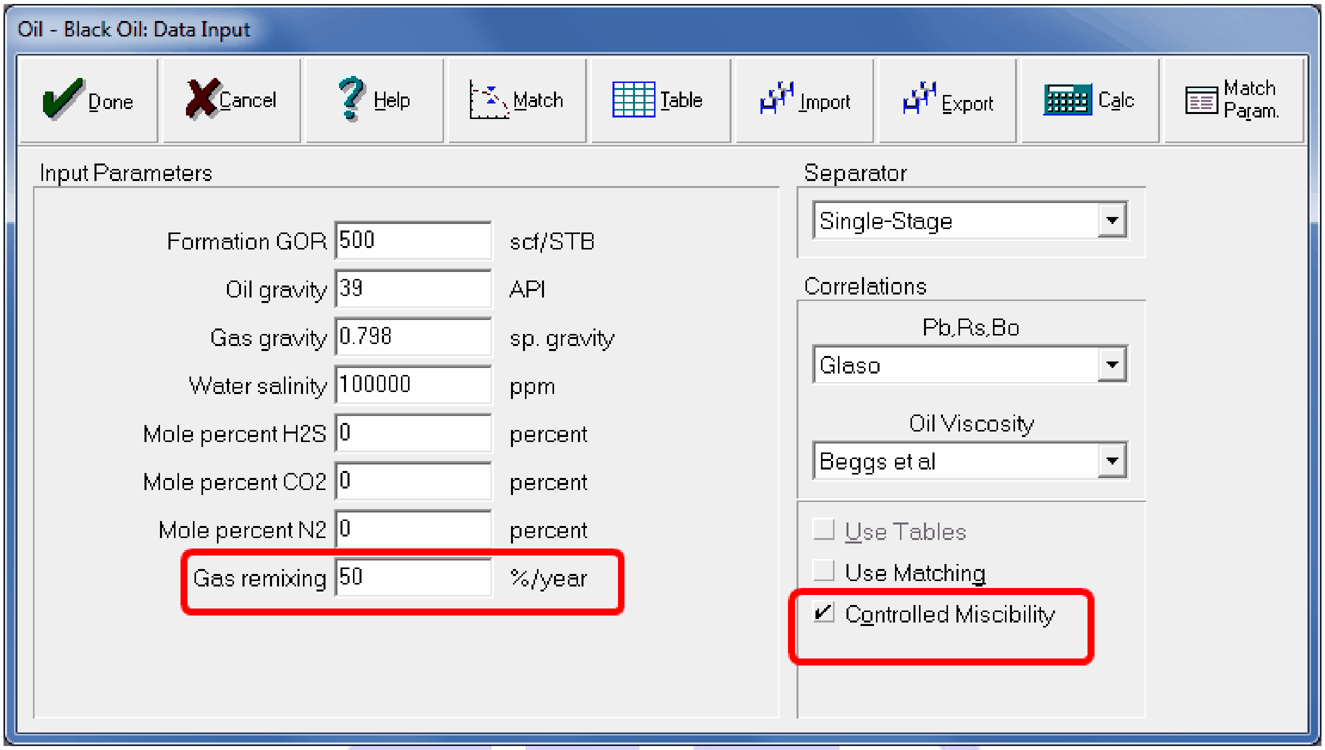
Command Buttons

Match	Displays a variable entry dialogue box in which measured PVT laboratory data can be entered to modify the selected correlations so that they fit the measured data
Table	Displays a variable entry screen in which the user can enter or import detailed PVT laboratory data. This command works with the 'Use Tables' flag. When the option is checked, the program uses the measured data provided in the tables. If **MBAL** requires data not provided in the tables, it will calculate the necessary parameters using the selected correlation
Import	Displays a dialogue to allow selection of a **PROSPER** PVT file to import into **MBAL**
Calc	Displays a dialogue box where calculations on PVT parameters are performed using the current PVT model. This can be used to verify the consistency of the PVT data entered
Match Param	Displays a dialogue to view or edit the current matching parameters. See PVT Matching Results for more information

.

2.3.4.2.3 Controlled Miscibility Option

This option is used to control how free gas redissolves into the oil if the pressure of the fluid increases.


Oil - Black Oil: Data Input

Input Parameters

Formation GOR 500 scf/STB
Oil gravity 39 API
Gas gravity 0.798 sp. gravity
Water salinity 100000 ppm
Mole percent H2S 0 percent
Mole percent CO2 0 percent
Mole percent N2 0 percent
Gas remixing 50 %/year

Separator: Single-Stage

Correlations
Pb,Rs,Bo: Glaso
Oil Viscosity: Beggs et al

☐ Use Tables
☐ Use Matching
☑ Controlled Miscibility

It is worth reviewing how gas re-dissolving was handled in older versions of **MBAL** (and how it is handled if this option is not selected).

Consider a reservoir for which the initial pressure is above the bubble point. As the pressure drops, the oil is in an undersaturated state and there would be no gas evolving out of the oil. This continues until the reservoir pressure drops to bubble point pressure. If the pressure continues to drop below the bubble point, gas will evolve out of the oil. The amount of gas is described by the saturated part of the Rs vs. Pressure curve as defined by the PVT model.

Now if the pressure of the fluid starts to increase, **MBAL** will use the predefined Rs vs. Pressure curve. In other words, we assume that the gas re-dissolves back into the oil at exactly the same rate as it bubbled out. If the pressure increases beyond the bubble point, **MBAL** keeps to the original Rs vs. Pressure curve. Therefore the amount of gas that can be re-dissolved back into the oil is limited to the initial solution GOR (Rs). So even if we have injected gas into the sample, it still cannot be dissolved into the oil above the initial Rs - no matter how high the pressure reaches.

So what are the changes if the controlled miscibility option is selected? In fact, as the pressure drops from the initial pressure, there is no change in the PVT model from before. The Rs will stay constant until the tank drops below the initial bubble point pressure - it will then decrease as specified by the saturated Rs vs. P curve. It is only if the pressure starts to increase that we see a change. Firstly, **MBAL** can now limit the amount of gas that can redissolve into the oil - this is specified by the gas remixing value (x) entered in the PVT dialogue. **MBAL** will keep track of the lowest value of Rs_{ref} during a prediction/simulation and use this as a reference point.

At each calculation step, **MBAL** does the following. It first calculates the maximum amount of gas that can be dissolved in the oil if limitless gas is available and the gas has infinite time to dissolve. It then calculates the maximum Rs available in the system i.e. the available gas to available oil ratio. It then sets the potential Rs (Rs_{POT}) to the minimum of these two values i.e. we are either limited by the available gas or the maximum gas that can dissolve. We then calculate the actual Rs to be:

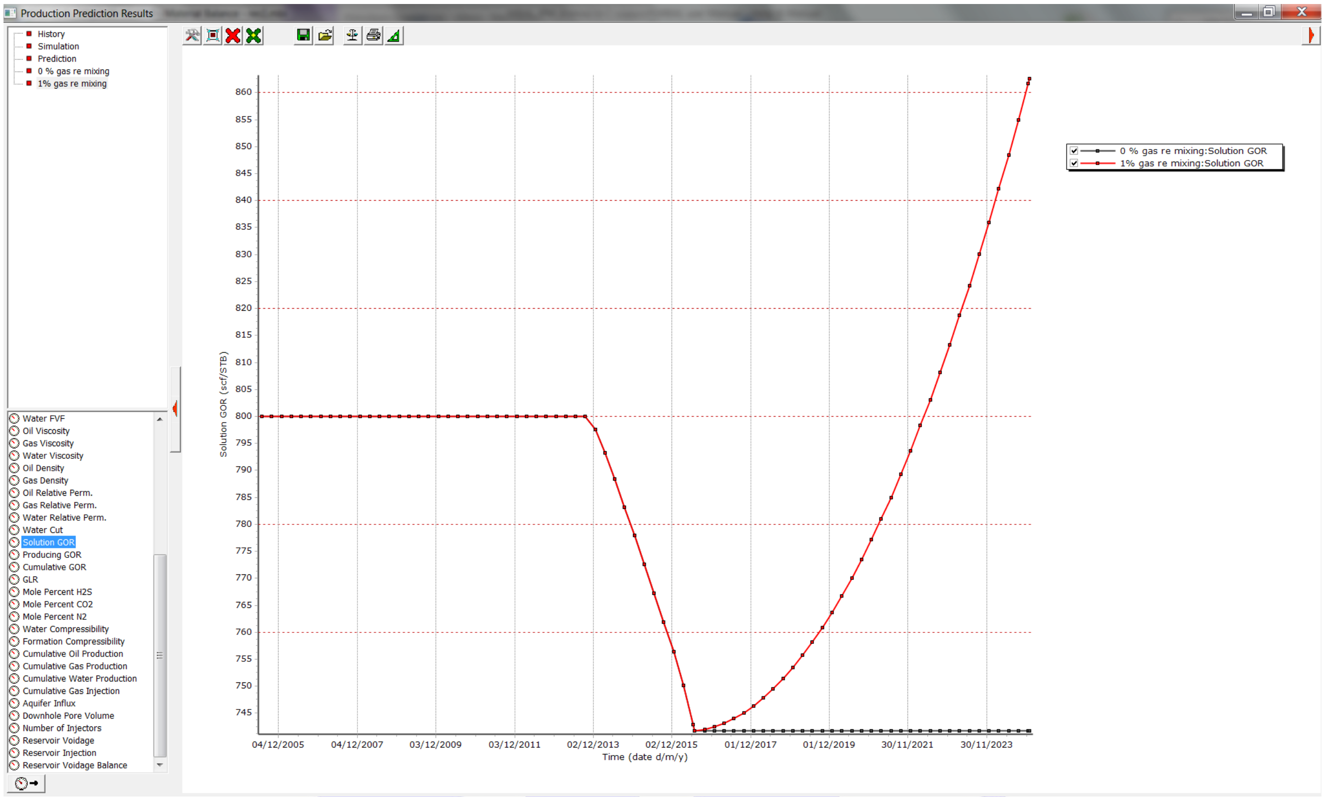
$$R_S = (1-x)R_{sLAST} + xR_{sPOT}$$

Rs_{LAST} is the Rs at the last time step. x is adjusted to be the remixing given the length of the time step. x is limited to a maximum of 1.0. If all of the gas is to be redissolved at each time step, then simply enter a very large number for the remixing e.g. 1.0e08. A value of 0.0 will mean that no remixing will occur.

Note that each time we calculate a new Rs, we also recalculate the corresponding new bubble point.

If the pressure rises above the initial pressure, **MBAL** will allow the Rs to rise above the initial Rs, assuming that the remixing factor is large enough, enough gas is available from injection and the oil can dissolve more gas. Note that if the pressure keeps rising, but the available gas runs out so the oil becomes under saturated again, **MBAL** will use fluid properties based on under saturated properties calculated from the new bubble point.

This can be seen in the graph below:


Production Prediction Results
History
Simulation
Prediction
0 % gas re mixing
1% gas re mixing
Water FVF
Oil Viscosity
Gas Viscosity
Water Viscosity
Oil Density
Gas Density
Oil Relative Perm.
Gas Relative Perm.
Water Relative Perm.
Water Cut
Solution GOR
Producing GOR
Cumulative GOR
GLR
Mole Percent H2S
Mole Percent CO2
Mole Percent N2
Water Compressibility
Formation Compressibility
Cumulative Oil Production
Cumulative Gas Production
Cumulative Water Production
Cumulative Gas Injection
Aquifer Influx
Downhole Pore Volume
Number of Injectors
Reservoir Voidage
Reservoir Injection
Reservoir Voidage Balance
Solution GOR (scf/STB)
860
855
850
845
840
835
830
825
820
815
810
805
800
795
790
785
780
775
770
765
760
755
750
745
04/12/2005
04/12/2007
03/12/2009
03/12/2011
02/12/2013
02/12/2015
01/12/2017
01/12/2019
30/11/2021
30/11/2023
Time (date d/m/y)
0 % gas re mixing:Solution GOR
1% gas re mixing:Solution GOR

There are three parts to this graph:

(1) Production from the reservoir above the bubble point
(2) The bubble point is reached, and production continues until 2015.
(3) From 2015 onwards gas injection occurs in the reservoir.

For the third point there are two scenarios: in scenario (i) the gas re mixing % is set to 0 and in scenario (ii) gas re mixing is set to 1%. It can be seen from the above plot that gas is reabsorbed by the oil phase as described above in the latter scenario.

2.3.4.2.4 Matching PVT correlations

The 'Match Data' input screen is used to adjust the empirical fluid property correlations to fit actual PVT laboratory measured data.

Correlations are modified using a non-linear regression technique to best fit the measured data. This facility can be accessed by clicking the **Match** command in the 'Fluid Properties' dialogue box or choosing **Pvt|Matching**.

Tables are sorted by temperature.

Input Parameters

- Enter a temperature and bubble (or dew) point value to match against

➡ **Flash data rather than differential liberation data should be used for matching**

Tables are sorted by temperature.

The PVT laboratory data to match against will vary depending on the 'Reservoir Fluid' selected in the **Options** menu.

Match Parameters

Oil	For each match table enter - Bubble Point, Pressure, GOR, Oil FVF and Oil Viscosity
Gas	For each match table enter - Gas Density, Z Factor (gas compressibility factor), Gas FVF and Gas Viscosity
Retrograde Condensate	For each match table enter - Dew Point, Pressure, Produced CGR (condensate to gas ratio), Z Factor (gas compressibility factor), Gas Viscosity and Gas FVF. The GOR separator does not require temperature and pressure data to be input in the match tables. The values entered in the 'Fluid Properties' input screen are used instead

When matching condensate density, there should be no input pressure higher than dew point, as the condensate density does not exist beyond that point.

- To select the next PVT table, check the next free radio button, or click **Next**.
- Click **Match** to select the fluid properties and correlation's to match.

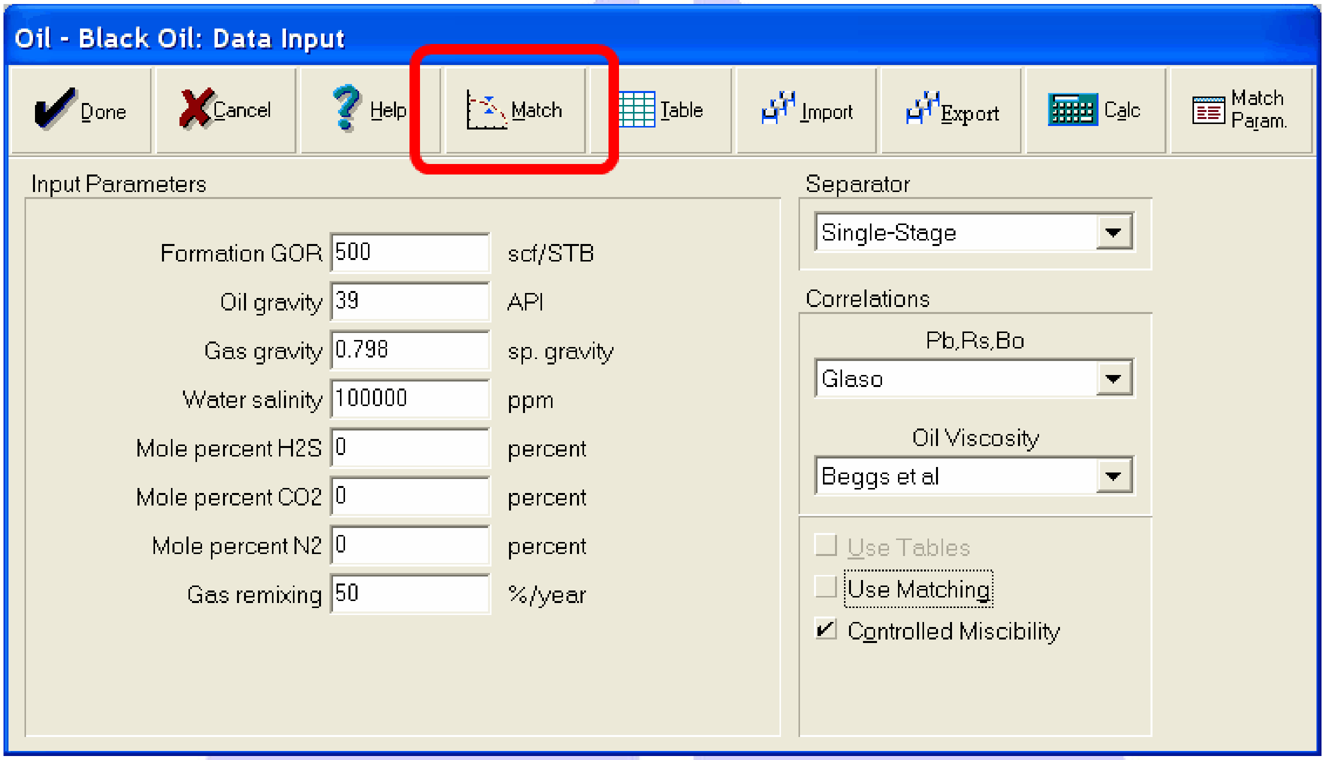
Command Buttons

Match	Displays the match calculation screen where the fluid properties and correlations to match against are selected. Correlations are modified using a non-linear regression technique. See match calculation for more information
Next	Displays the next PVT input table. See PVT Tables 91 for more information

2.3.4.2.5 Matching correlations

There are several correlations available to model the fluid behaviour with changing pressure and temperature. By carrying out the 'Matching' system, the most appropriate correlation can be selected and 'Matched' to the actual fluid properties themselves. This is to ensure that the predicted fluid behaviour as calculations are run, is reproducing the actual behaviour of the fluid being modelled (and not just closely).

The correlations are modified using a non-linear regression technique to best fit the measured data. This facility is accessed by clicking the **Match** command in the 'Fluid Properties' dialogue box:


Oil - Black Oil: Data Input
Done
Cancel
Help
Match
Table
Import
Export
Calc
Match Param.

Input Parameters

Formation GOR	500	scf/STB
Oil gravity	39	API
Gas gravity	0.798	sp. gravity
Water salinity	100000	ppm
Mole percent H2S	0	percent
Mole percent CO2	0	percent
Mole percent N2	0	percent
Gas remixing	50	%/year

Separator: Single-Stage

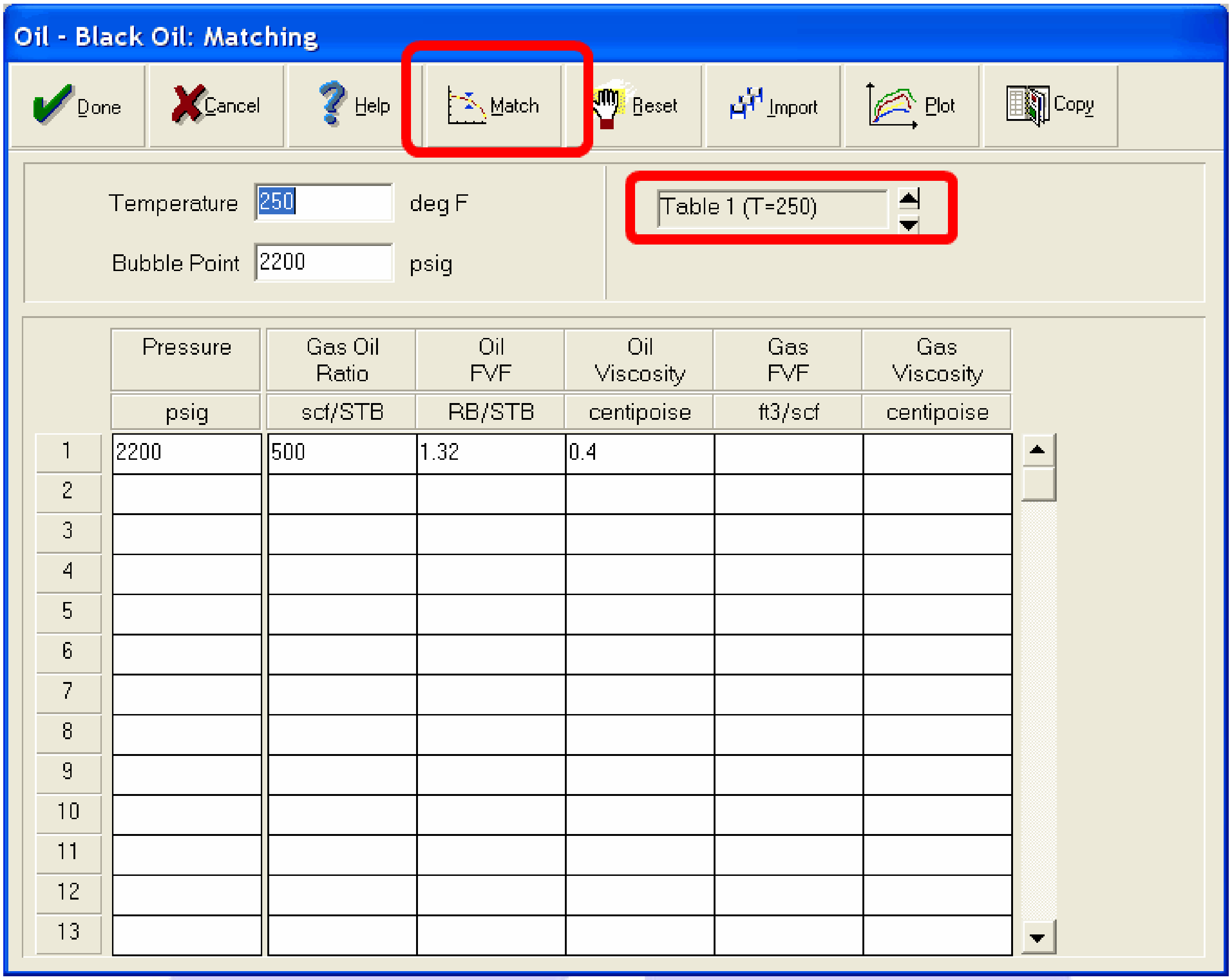
Correlations

Pb,Rs,Bo: Glaso

Oil Viscosity: Beggs et al

☐ Use Tables
☐ Use Matching
☑ Controlled Miscibility

The following screen will appear:



Temperature 250 deg F

Bubble Point 2200 psig

Table 1 (T=250)

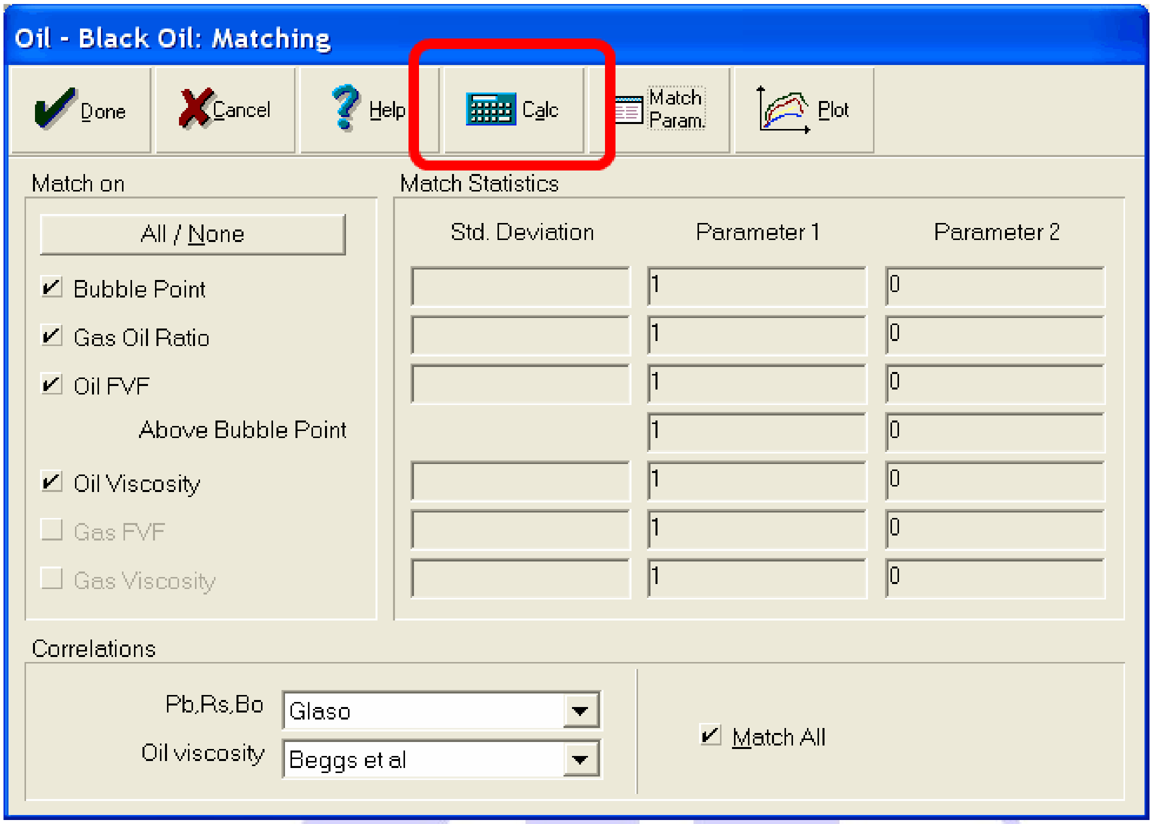
	Pressure	Gas Oil Ratio	Oil FVF	Oil Viscosity	Gas FVF	Gas Viscosity
	psig	scf/STB	RB/STB	centipoise	ft3/scf	centipoise
1	2200	500	1.32	0.4		
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						

Up to 50 PVT tables can be entered which are sorted by temperature.

The available match data can be entered manually or imported using the “Import” button in this screen (from a file of **PVTP** for instance).

➲ **The data entered for matching should be from a CCE experiment in order to ensure mass balance consistency in the data**

Once all the data has been entered, click **Match** as shown above in order to match the correlations to the available data.



Match on

☑ Bubble Point
☑ Gas Oil Ratio
☑ Oil FVF
Above Bubble Point
☑ Oil Viscosity
☐ Gas FVF
☐ Gas Viscosity

Match Statistics

	Std. Deviation	Parameter 1	Parameter 2
Bubble Point		1	0
Gas Oil Ratio		1	0
Oil FVF		1	0
Above Bubble Point		1	0
Oil Viscosity		1	0
Gas FVF		1	0
Gas Viscosity		1	0

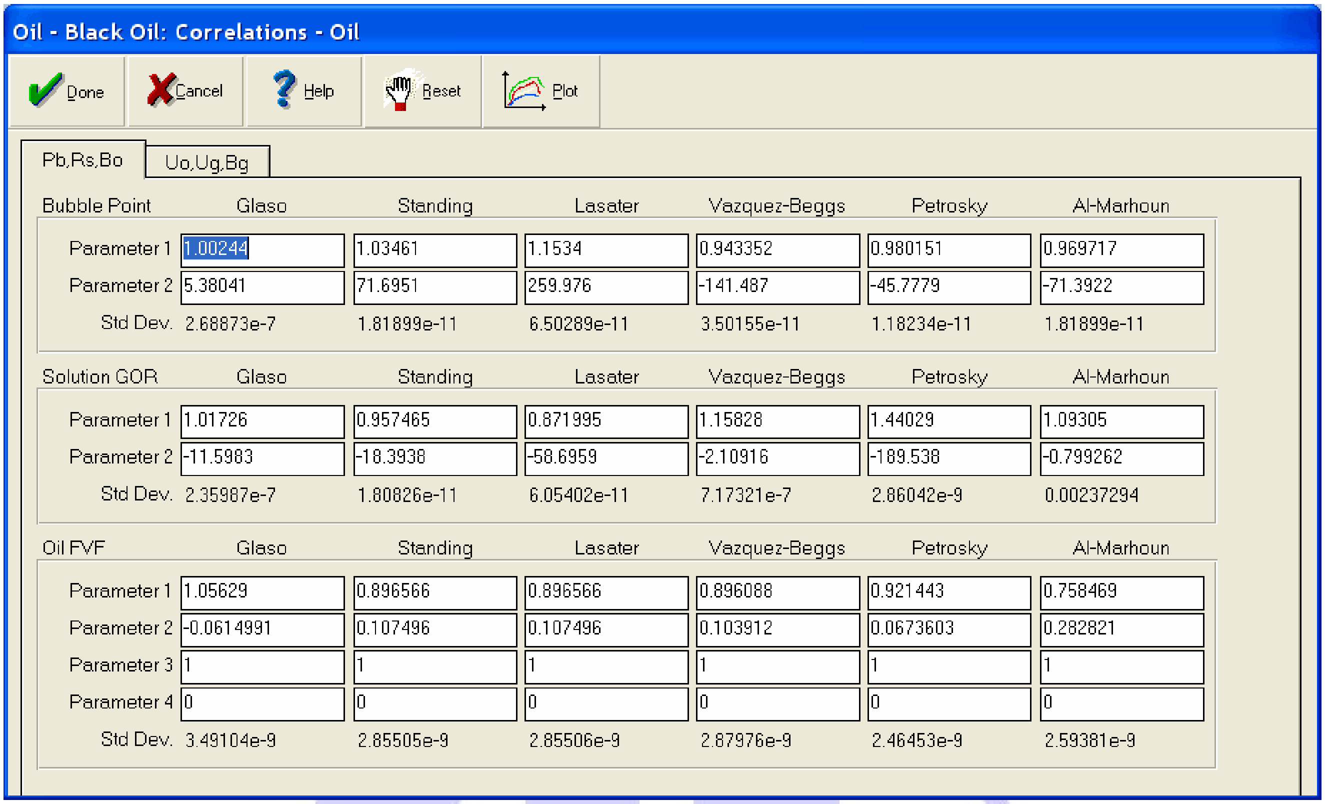
Correlations

Pb,Rs,Bo: Glaso
Oil viscosity: Beggs et al

☑ Match All

Click **Calc** to start the match process. The regression technique applies a multiplier (**Parameter 1**), and a shift (**Parameter 2**) to the correlation. The **Standard Deviation** displays the overall match quality. The lower the standard deviation, the better the match.

When the calculations have been carried out, the match coefficients for the selected correlations and fluid properties are displayed under **Match Parameters**:



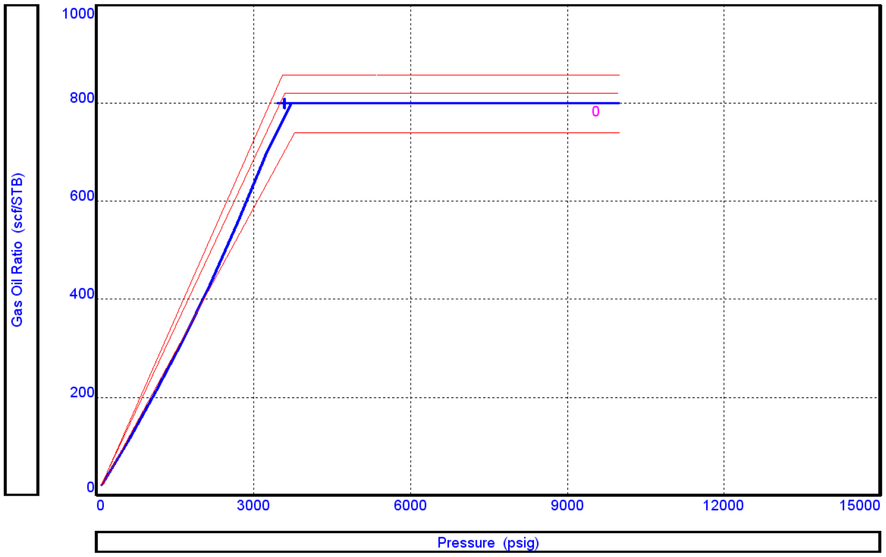
Bubble Point	Glaso	Standing	Lasater	Vazquez-Beggs	Petrosky	Al-Marhoun
Parameter 1	1.00244	1.03461	1.1534	0.943352	0.980151	0.969717
Parameter 2	5.38041	71.6951	259.976	-141.487	-45.7779	-71.3922
Std Dev.	2.68873e-7	1.81899e-11	6.50289e-11	3.50155e-11	1.18234e-11	1.81899e-11

Solution GOR	Glaso	Standing	Lasater	Vazquez-Beggs	Petrosky	Al-Marhoun
Parameter 1	1.01726	0.957465	0.871995	1.15828	1.44029	1.09305
Parameter 2	-11.5983	-18.3938	-58.6959	-2.10916	-189.538	-0.799262
Std Dev.	2.35987e-7	1.80826e-11	6.05402e-11	7.17321e-7	2.86042e-9	0.00237294

Oil FVF	Glaso	Standing	Lasater	Vazquez-Beggs	Petrosky	Al-Marhoun
Parameter 1	1.05629	0.896566	0.896566	0.896088	0.921443	0.758469
Parameter 2	-0.0614991	0.107496	0.107496	0.103912	0.0673603	0.282821
Parameter 3	1	1	1	1	1	1
Parameter 4	0	0	0	0	0	0
Std Dev.	3.49104e-9	2.85505e-9	2.85506e-9	2.87976e-9	2.46453e-9	2.59381e-9

From these tables, the best correlation (the one requiring the least correction) can be selected. This should have parameter 1 as close to 1 as possible and parameter 2 as close to 0 as possible.

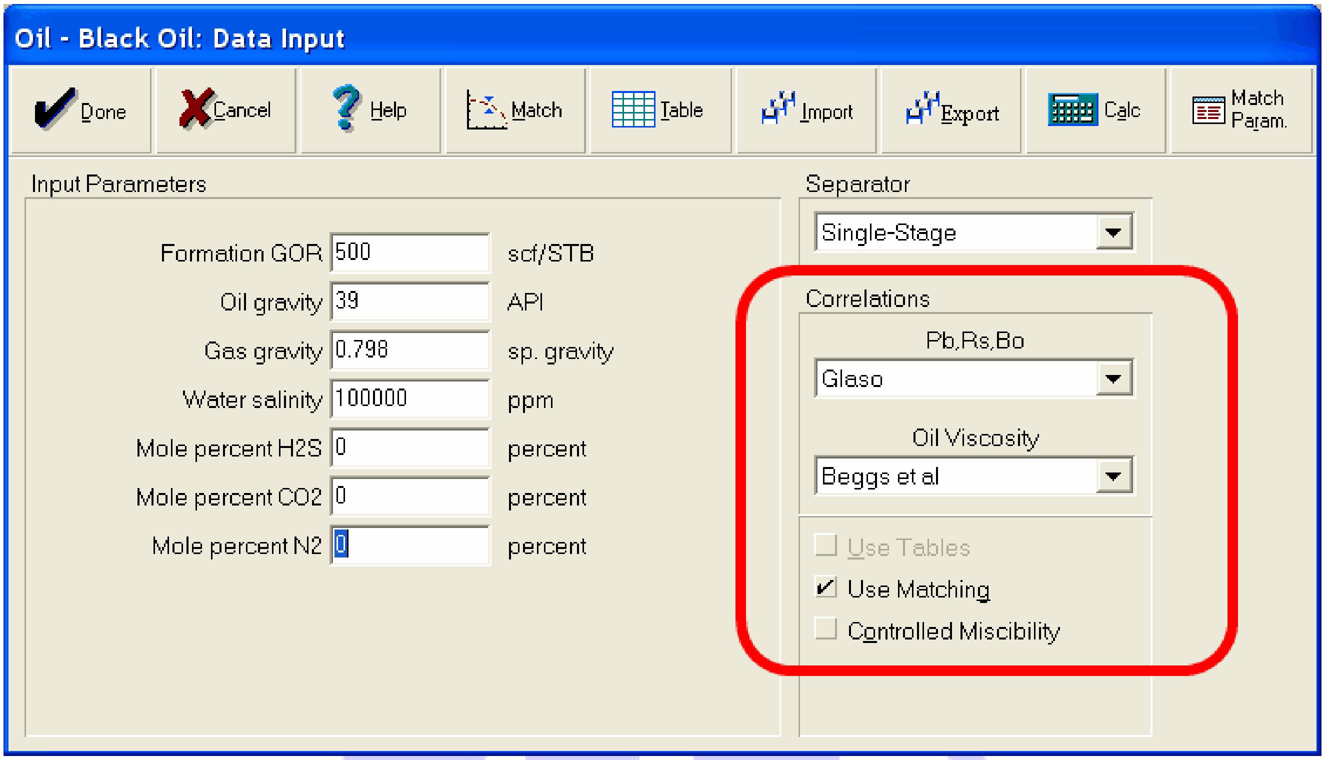
Different correlations will calculate different results.
Corrections are applied to the plots obtained from different correlations to ensure that the actual measured data can be reproduced.
Taking a plot of GOR with pressure, the correlation which calculates the plot requiring the least correction would be the most desirable.
The parameter values are the multipliers in the linear equation: y = a x + b.



The corrections are Parameter 1 and 2.
As Parameter 1 [a] is a multiplier it needs to be as close to 1 as possible.
As Parameter 2 [b] is an addition, it needs to be as close to 0 as possible.

➡ ***To unmatch correlations*, click Reset. All matching parameters will be reset to 1 and 0 respectively.**

The correlations selected can then be applied in the program from the main PVT screen:



Input Parameters

Formation GOR	500	scf/STB
Oil gravity	39	API
Gas gravity	0.798	sp. gravity
Water salinity	100000	ppm
Mole percent H2S	0	percent
Mole percent CO2	0	percent
Mole percent N2	0	percent

Separator: Single-Stage

Correlations

Pb,Rs,Bo: Glaso

Oil Viscosity: Beggs et al

☐ Use Tables

☑ Use Matching

☐ Controlled Miscibility

2.3.4.2.6 Using PVT tables

If PVT laboratory data is available it can be entered in the tables provided. The program will:

- Use the data in the PVT tables in all calculations instead of the correlations. To use the PVT tables, the 'Use Tables' flag must be enabled.
- Where MBAL requires data that is not entered in the tables, the program will calculate the parameters using the selected correlation method.

Input Parameters

- Enter the required basic PVT information in the 'Fluid Properties' data entry screen
- Select the correlation known to best fit the region or fluid type
- Check the 'Use Tables' option in the data input screen, and click 'Tables'
- Enter the measured PVT data in the columns provided

Up to 50 PVT tables can be entered, and each table may use a different temperature if desired. Tables are sorted by temperature. Where the program requires data that is not entered in the tables, it will calculate it using the selected correlation method.

See PVT Oil Tables, PVT Gas Tables or PVT Retrograde Condensate Tables for more information.

PVT Table Parameters

Oil	For each table enter a temperature along with: Bubble Point, Pressure, Gas Oil Ratio, Oil FVF and Oil Viscosity, Oil Density, Oil Compressibility, Gas FVF, Gas Viscosity, Water Viscosity, Water compressibility and Formation compressibility
Gas	For each match table enter a temperature along with: Pressure, Z Factor (gas compressibility factor), Gas Viscosity, Gas FVF, Gas Density, Water Viscosity, Water compressibility, and Formation compressibility
Retrograde **Condensate**	For each match table enter a temperature along with: Pressure, Z Factor (gas compressibility factor), Gas Viscosity, Gas FVF, Gas Density, Water Viscosity, Water compressibility and Formation compressibility

To open the next PVT table, check the next free radio button, and click **Next**, or **Import**.

If no further data is available, click ***Done*** to exit the PVT menu.

Command Buttons

Reset	Resets the contents of one or all the PVT Tables. Select the relevant option, and click 'Done' to confirm the table deletion. Click 'Cancel' to ignore
Import	Displays a file import dialogue box. The user will be prompted to enter a file name and select the appropriate import file type. See importing files for more information
Plot	Allows plotting of a single chosen variable (e.g. Oil FVF, Gas Viscosity) against pressure or temperature. All the tables are plotted at the same time
Copy	Copy a set of table/match data from another section of the program data

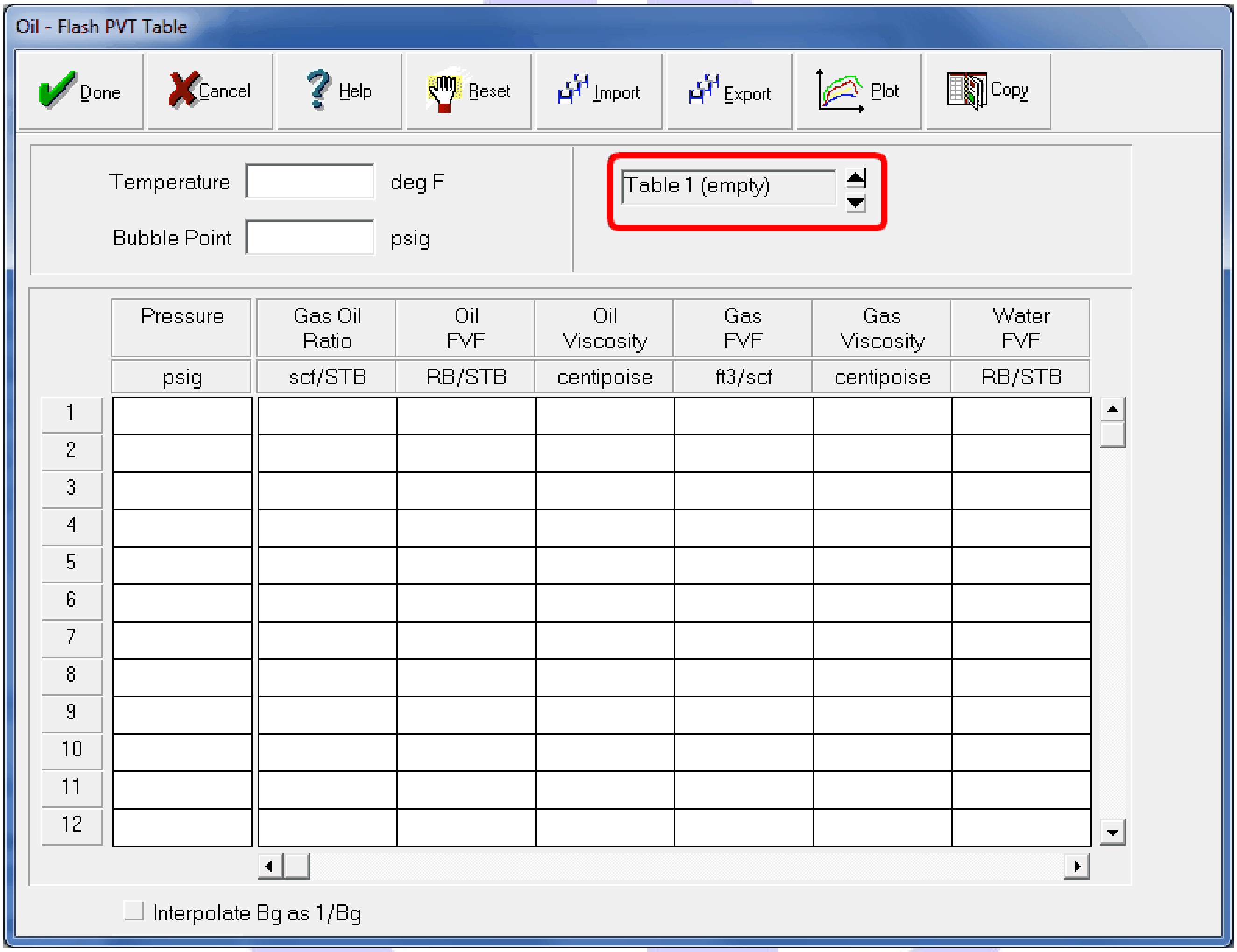
If detailed PVT laboratory data is available it can be entered in the tables provided. The program will use the data in the PVT entered in the tables only in all further calculations if the '**Use Tables**' option in the 'Fluid Properties' data entry screen is enabled.

Note on use of tables: Tables are usually generated using one fluid composition which implies a single GOR for the fluid. This will therefore not provide the right fluid description when we have injection of hydrocarbons in the reservoir (for pressure support for instance).

Example of table entry

Up to 50 PVT tables can be entered, and each table may use a different temperature if desired. Tables are sorted by temperature. Should the software require data that has not been entered in the tables, this data will be calculated using correlations.
To access the PVT tables:

- Enter the information required in the input dialogue box. Check the 'Use Tables' option in the data input screen, and click **Tables**. A 'User Table' dialogue box similar to the following will appear:


Oil - Flash PVT Table
Done
Cancel
Help
Reset
Import
Export
Plot
Copy
Temperature
deg F
Bubble Point
psig
Table 1 (empty)
Pressure psig
Gas Oil Ratio scf/STB
Oil FVF RB/STB
Oil Viscosity centipoise
Gas FVF ft3/scf
Gas Viscosity centipoise
Water FVF RB/STB
1
2
3
4
5
6
7
8
9
10
11
12
Interpolate Bg as 1/Bg

- Enter the measured PVT data in the columns provided. To select the next PVT table, scroll to the next free table from the up/down button shown above.

The **Import** facility is an alternative method of entering data. The option is open to any user who would like to use data from their own programs. As file formats vary across programs, this option is user specific. The general file import facility is described in the chapter referring to

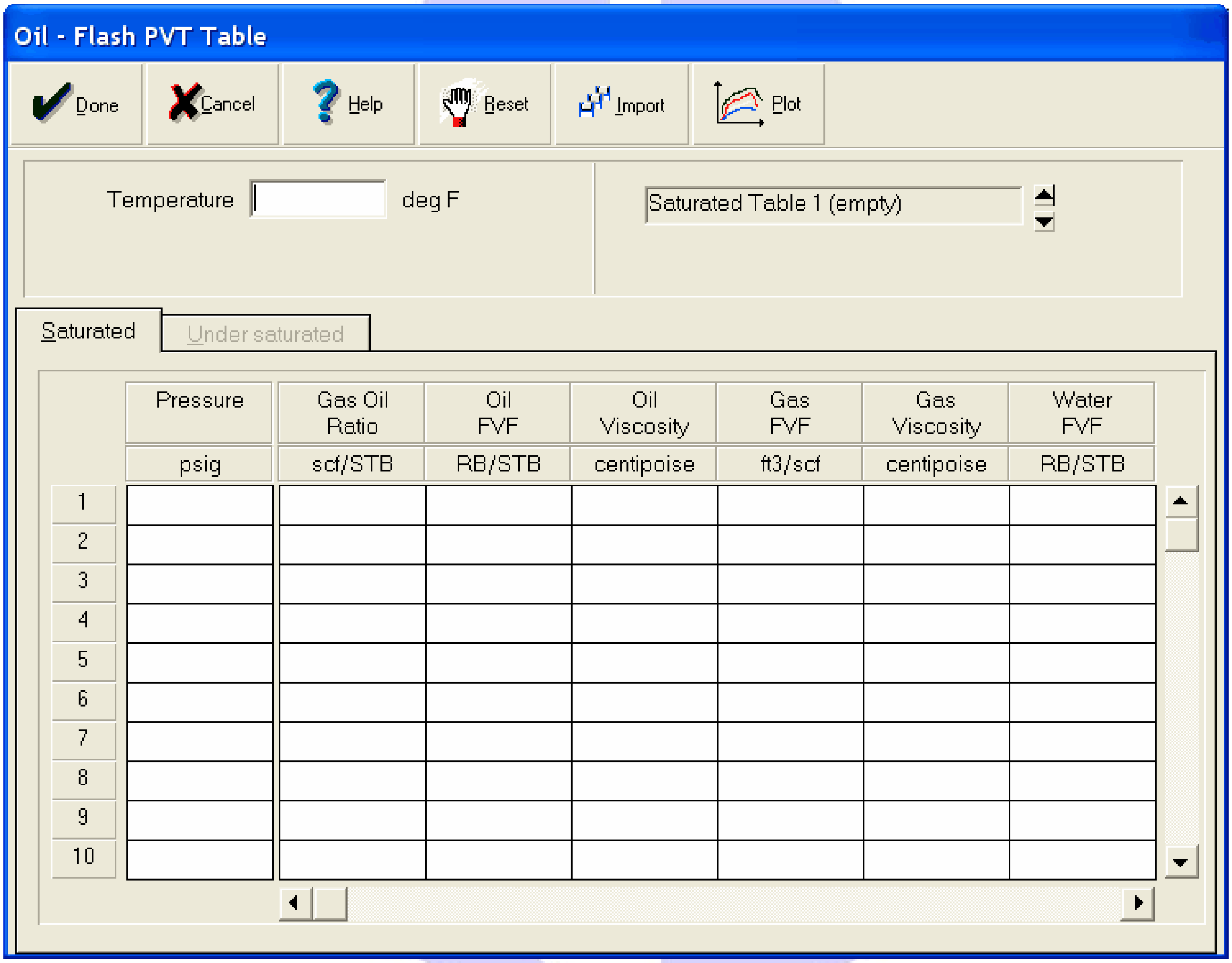
Data Imports 45.

For the material balance tool, if a fixed value for water compressibility has been entered in the tank data, the tool will ignore any values entered for Bw in the PVT tables.

If no further data is available, click ***Done*** to exit the PVT menu.

2.3.4.2.7 PVT Tables for Controlled Miscibility

If controlled miscibility has been selected, the table entry has some differences. As before, one can enter up to 50 tables with a different temperature for each set. However for each temperature one must enter a single saturated table and up to 50 under-saturated tables. Each under-saturated table corresponds to a different bubble point.



Temperature [ ] deg F

Saturated Table 1 (empty)

	Pressure	Gas Oil Ratio	Oil FVF	Oil Viscosity	Gas FVF	Gas Viscosity	Water FVF
	psig	scf/STB	RB/STB	centipoise	ft3/scf	centipoise	RB/STB
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

If PVT laboratory data is available it can be entered in the tables provided. The program will:

- Use the data in the PVT tables in all calculations instead of the correlations. To use the PVT tables, the 'Use Tables' flag must be enabled.
- Where MBAL requires data that is not entered in the tables, the program will calculate the parameters using the selected correlation method.

Input Parameters

- Enter the required basic PVT information in the 'Fluid Properties' data entry screen
- Select the correlation known to best fit the region or fluid type
- Check the 'Use Tables' option in the data input screen, and click 'Tables'
- Enter the measured PVT data in the columns provided

Up to 50 PVT tables can be entered, and each table may use a different temperature if desired. Tables are sorted by temperature. Where the program requires data that is not entered in the tables, it will calculate it using the selected correlation method.

See PVT Oil Tables, PVT Gas Tables or PVT Retrograde Condensate Tables for more information.

PVT Table Parameters

Oil	For each table enter a temperature along with: Bubble Point, Pressure, Gas Oil Ratio, Oil FVF and Oil Viscosity, Oil Density, Oil Compressibility, Gas FVF, Gas Viscosity, Water Viscosity, Water compressibility and Formation compressibility
Gas	For each match table enter a temperature along with: Pressure, Z Factor (gas compressibility factor), Gas Viscosity, Gas FVF, Gas Density, Water Viscosity, Water compressibility, and Formation compressibility
Retrograde **Condensate**	For each match table enter a temperature along with: Pressure, Z Factor (gas compressibility factor), Gas Viscosity, Gas FVF, Gas Density, Water Viscosity, Water compressibility and Formation compressibility

To open the next PVT table, check the next free radio button, and click **Next**, or **Import**.

If no further data is available, click ***Done*** to exit the PVT menu.

Command Buttons

Reset	Resets the contents of one or all the PVT Tables. Select the relevant option, and click 'Done' to confirm the table deletion. Click 'Cancel' to ignore

Import	Displays a file import dialogue box. The user will be prompted to enter a file name and select the appropriate import file type. See importing files for more information
Plot	Allows plotting of a single chosen variable (e.g. Oil FVF, Gas Viscosity) against pressure or temperature. All the tables are plotted at the same time
Copy	Copy a set of table/match data from another section of the program data

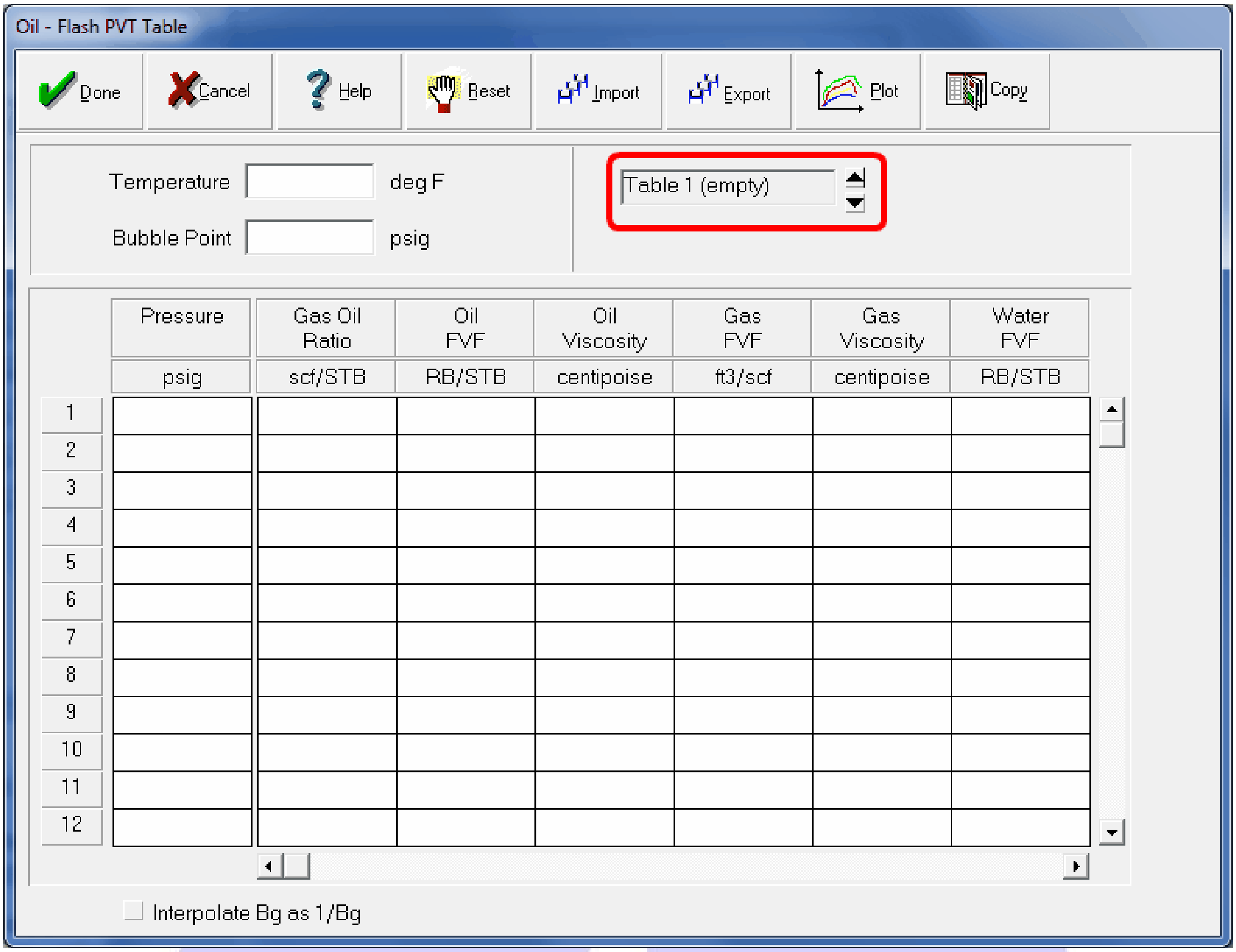
If detailed PVT laboratory data is available it can be entered in the tables provided. The program will use the data in the PVT entered in the tables only in all further calculations if the '**Use Tables**' option in the 'Fluid Properties' data entry screen is enabled.

Note on use of tables: Tables are usually generated using one fluid composition which implies a single GOR for the fluid. This will therefore not provide the right fluid description when we have injection of hydrocarbons in the reservoir (for pressure support for instance).

Example of table entry

Up to 50 PVT tables can be entered, and each table may use a different temperature if desired. Tables are sorted by temperature. Should the software require data that has not been entered in the tables, this data will be calculated using correlations.
To access the PVT tables:

- Enter the information required in the input dialogue box. Check the 'Use Tables' option in the data input screen, and click **Tables**. A 'User Table' dialogue box similar to the following will appear:


Oil - Flash PVT Table
Done
Cancel
Help
Reset
Import
Export
Plot
Copy
Temperature
deg F
Bubble Point
psig
Table 1 (empty)
Interpolate Bg as 1/Bg

	Pressure psig	Gas Oil Ratio scf/STB	Oil FVF RB/STB	Oil Viscosity centipoise	Gas FVF ft3/scf	Gas Viscosity centipoise	Water FVF RB/STB
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							

- Enter the measured PVT data in the columns provided. To select the next PVT table, scroll to the next free table from the up/down button shown above.

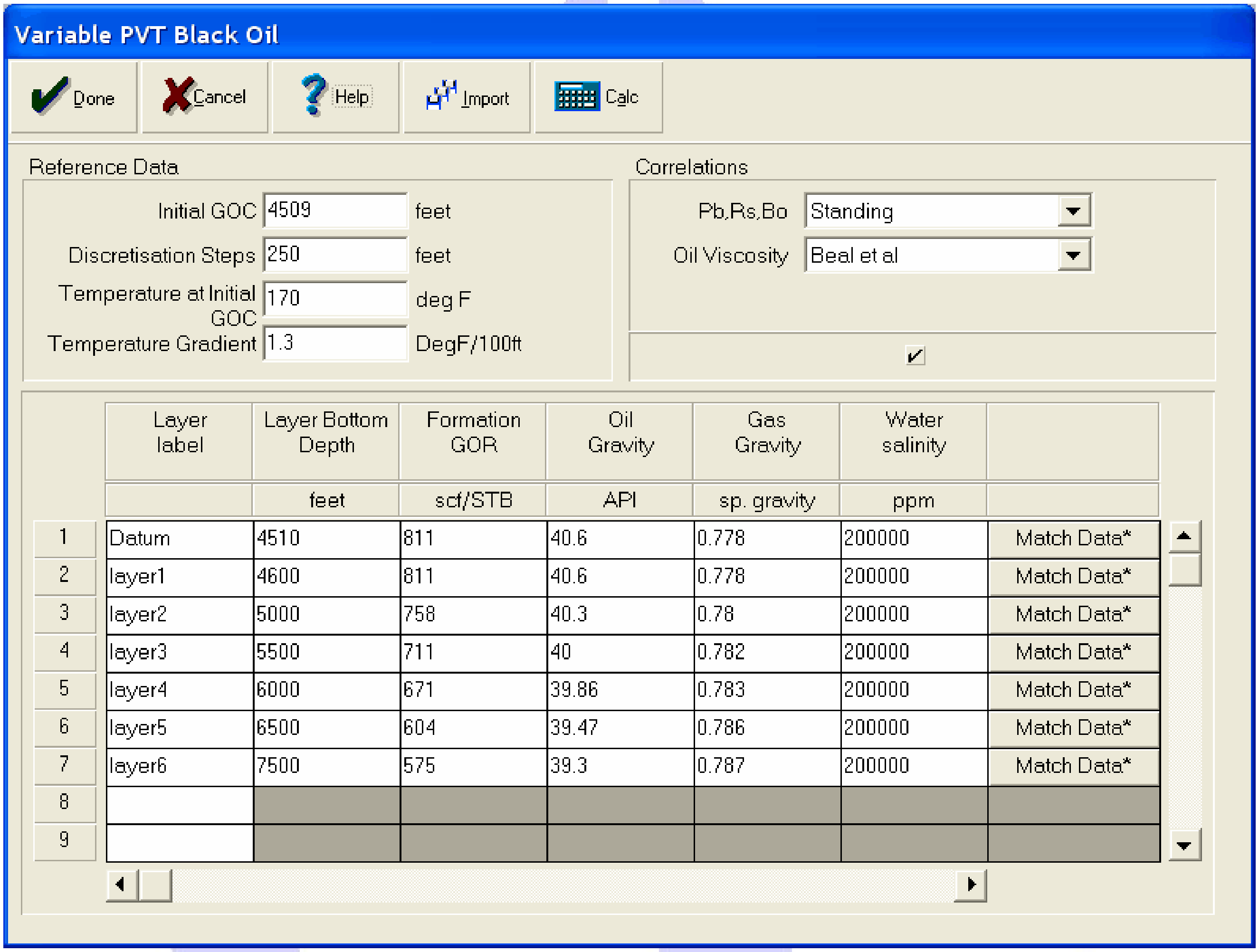
The **Import** facility is an alternative method of entering data. The option is open to any user who would like to use data from their own programs. As file formats vary across programs, this option is user specific. The general file import facility is described in the chapter referring to Data Imports 45.

For the material balance tool, if a fixed value for water compressibility has been entered in the tank data, the tool will ignore any values entered for Bw in the PVT tables.

If no further data is available, click ***Done*** to exit the PVT menu.

2.3.4.2.8 Variable PVT for Oil Reservoir

The 'Variable PVT Black Oil' screen appears if oil is defined as the reservoir fluid type in the **Options** menu and 'Variable PVT' as the PVT model. This model attempts to take into account the change in black oil properties versus depth.



Reference Data

Initial GOC: 4509 feet
Discretisation Steps: 250 feet
Temperature at Initial GOC: 170 deg F
Temperature Gradient: 1.3 DegF/100ft

Correlations

Pb,Rs,Bo: Standing
Oil Viscosity: Beal et al

	Layer label	Layer Bottom Depth	Formation GOR	Oil Gravity	Gas Gravity	Water salinity	
		feet	scf/STB	API	sp. gravity	ppm	
1	Datum	4510	811	40.6	0.778	200000	Match Data*
2	layer1	4600	811	40.6	0.778	200000	Match Data*
3	layer2	5000	758	40.3	0.78	200000	Match Data*
4	layer3	5500	711	40	0.782	200000	Match Data*
5	layer4	6000	671	39.86	0.783	200000	Match Data*
6	layer5	6500	604	39.47	0.786	200000	Match Data*
7	layer6	7500	575	39.3	0.787	200000	Match Data*
8							
9							

In this model, the tank is divided into several ‘layers’ having different PVT properties. Describe the average PVT properties of each layer. If measured data is available, do not forget to match each layer PVT correlations by clicking on the **Match Data** button.

The depths entered here must match the depths entered in the reservoir Pore Volume vs Depth Table. Enter the **Initial GOC** which should correspond to the 0 pore volume vs depth - it also defines the top of the top layer. The bottom of the bottom layer should correspond to the 1.0 pore volume vs depth.

➡ Since the initial GOC defines the top of the top layer, all layer bottom depths must be greater than the initial GOC. **MBAL** will sort the layers in the table by the layer bottom depth. **MBAL** will not allow layers of less than one foot thick to be entered

Within the calculations, **MBAL** splits layers into further sub-layers to increase the accuracy of the calculations. The default sub-layer size is 250 feet (76.2m). However if it is desired to use smaller sub-layers to further increase accuracy or use larger sub-layers to increase calculation speeds then this value can be changed by editing the **Discretisation Steps** value.

Enter the following:

Input Parameters

Enter the required fluid data in the fields provided.

PVT Layers	Enter the fluid data which is specific to each layer. If a new layer is to be added, click on the ***Layer Label*** of the next free row in the table and enter a new label. This will enable the other fields in the new row and the relevant fluid data will then be entered. If additional PVT data is to be matched to the correlations, click on the ***Match Data*** field at the end of the row. Note that a '*' will be visible on the ***Match Data*** button if the match process has already been performed on a layer. Selecting the layer number field to depress the button will disable the PVT layer for that row. Click on the layer number button again and it will re-enable the row
Correlations	Select the black oil correlations best known to fit the fluid type

➡ The formation GOR is the s**olution GOR** at the bubble point and should not include free gas production

➡ The Mole Percent, CO2, N2 and H2S are from gas stream composition

Where additional PVT data can be supplied:

Use Matching	Check the 'Use Matching' box if the matched black oil correlations are to be used. See PVT Oil Match for more information. Disallow (uncheck) this option, if it is decided to use the ***original unmatched*** black oil correlations. This button will be disabled if no matching data has been calculated. Click the ***Match Data*** buttons in the PVT layers table to enter matching data and calculate matching parameters for each layer. See PVT Matching Input Screen 84 for more information

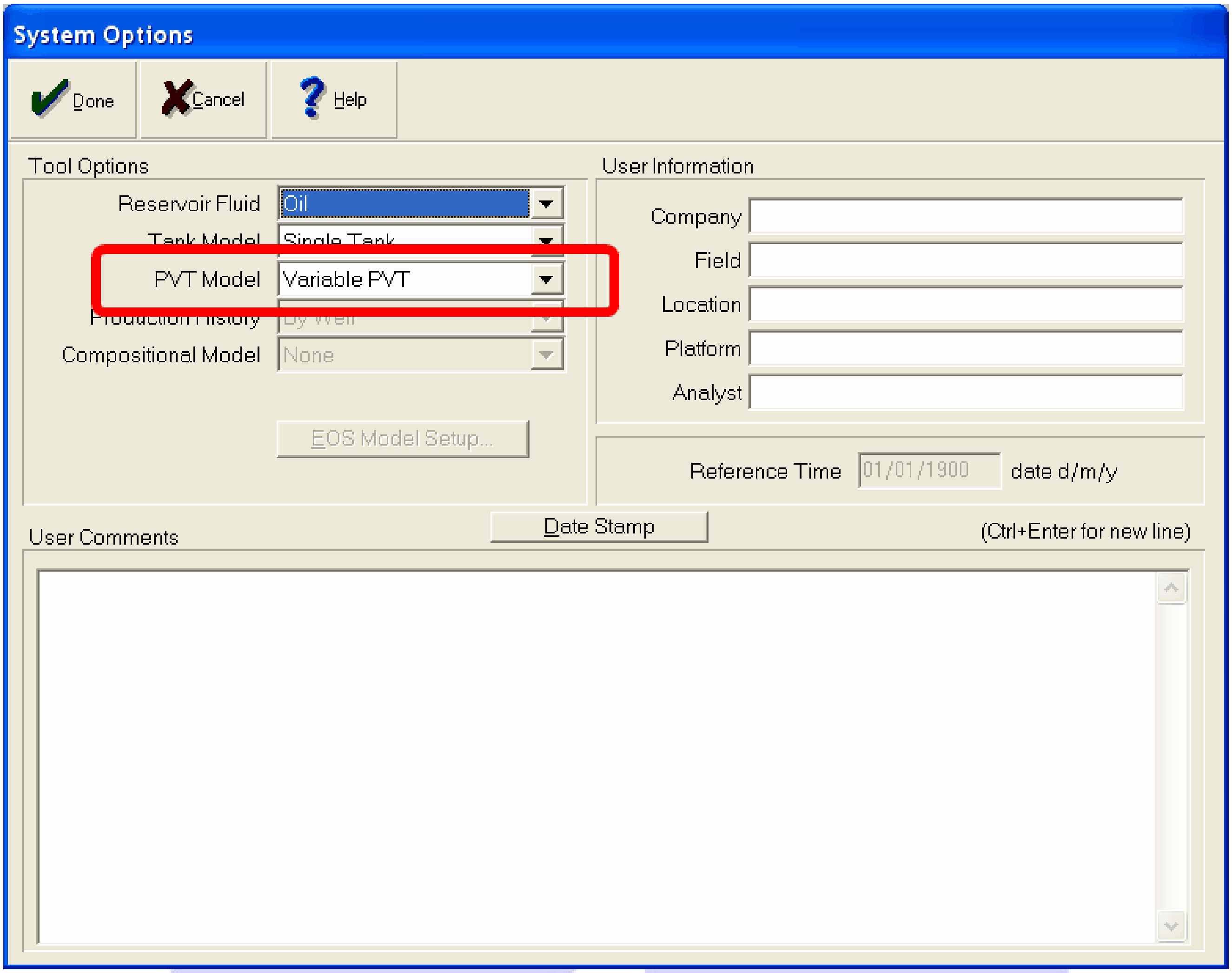
Command Buttons

Import	Displays a dialogue to allow selection of a **PROSPER** .PVT or **PVTP** .PGD file to import into **MBAL**.

	To import a PVT file (which contains a single set of PVT data), either click on an row with data or click on an empty row in the ***PVT Layers*** table. Ensuring that the focus is still in the row, click on the ***Import*** button. The new PVT data will be loaded into the row. ➡ If the focus is on a row with data when ***Import*** is clicked, the existing row will be over-written without any warning. To import a PGD file (which contains a number of sets of PVT data), simply select the Import button. ➡ If any PVT Layers have been set up in the dialogue, they will be del warning when importing a PGD file See Import Variable PVT for more information
Calc	Displays a dialogue box where calculations on PVT parameters are performed using the current PVT model. This can be used to verify the consistency of the PVT data entered. See PVT Fluid Properties Calculation Input Screen for more information

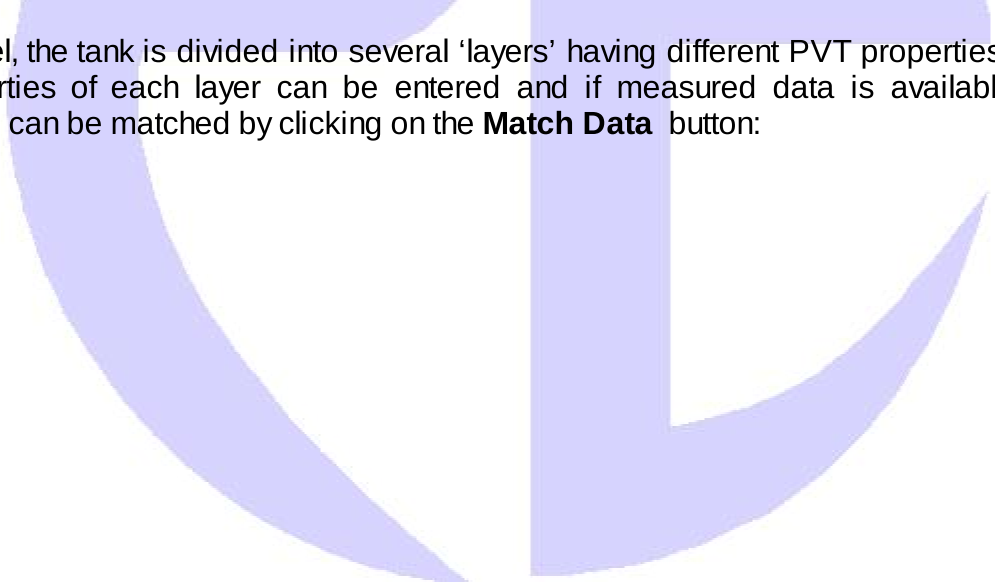
Example entry

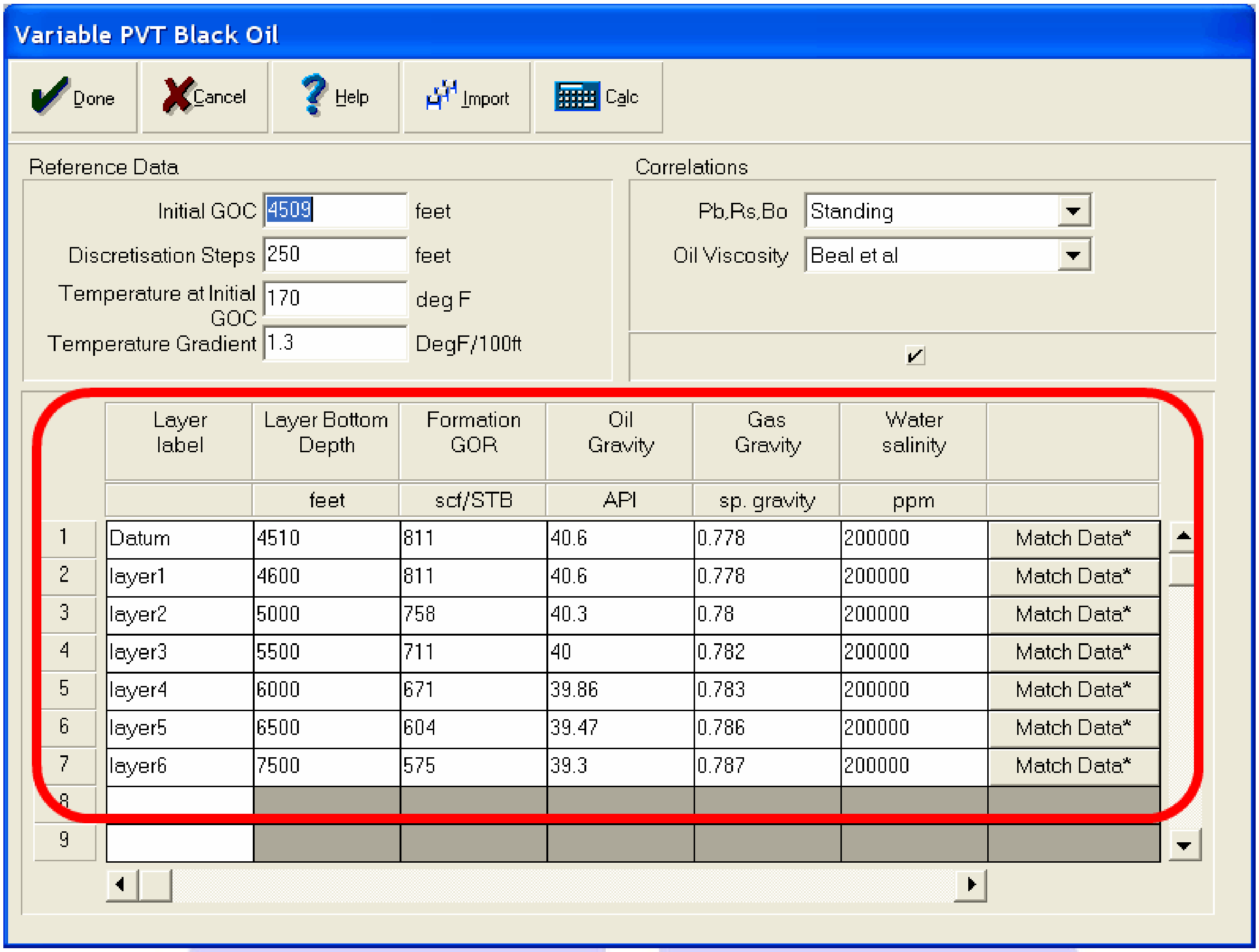
In order to account for the change of black oil properties versus depth (compositional gradient), a ‘Variable PVT’ tank model has been implemented. To enable this tank model, select ‘Variable PVT’ as the tank model in the **Options** menu:


System Options
Done
Cancel
Help
Tool Options
User Information
Company
Field
Location
Platform
Analyst
EOS Model Setup...
Date Stamp
(Ctrl+Enter for new line)
User Comments

Reservoir Fluid: Oil
Tank Model: Single Tank
PVT Model: Variable PVT
Production History: By Well
Compositional Model: None
Reference Time: 01/01/1900 date d/m/y

In this model, the tank is divided into several ‘layers’ having different PVT properties. The basic PVT properties of each layer can be entered and if measured data is available, the PVT correlations can be matched by clicking on the **Match Data** button:





Reference Data

Initial GOC 4509 feet

Discretisation Steps 250 feet

Temperature at Initial GOC 170 deg F

Temperature Gradient 1.3 DegF/100ft

Correlations

Pb,Rs,Bo Standing

Oil Viscosity Beal et al

☑

	Layer label	Layer Bottom Depth	Formation GOR	Oil Gravity	Gas Gravity	Water salinity	
		feet	scf/STB	API	sp. gravity	ppm	
1	Datum	4510	811	40.6	0.778	200000	Match Data*
2	layer1	4600	811	40.6	0.778	200000	Match Data*
3	layer2	5000	758	40.3	0.78	200000	Match Data*
4	layer3	5500	711	40	0.782	200000	Match Data*
5	layer4	6000	671	39.86	0.783	200000	Match Data*
6	layer5	6500	604	39.47	0.786	200000	Match Data*
7	layer6	7500	575	39.3	0.787	200000	Match Data*
8							
9							

➲ **Note that an asterisk sign '*' will appear on the Match Data button if the match process has already been performed on a layer**

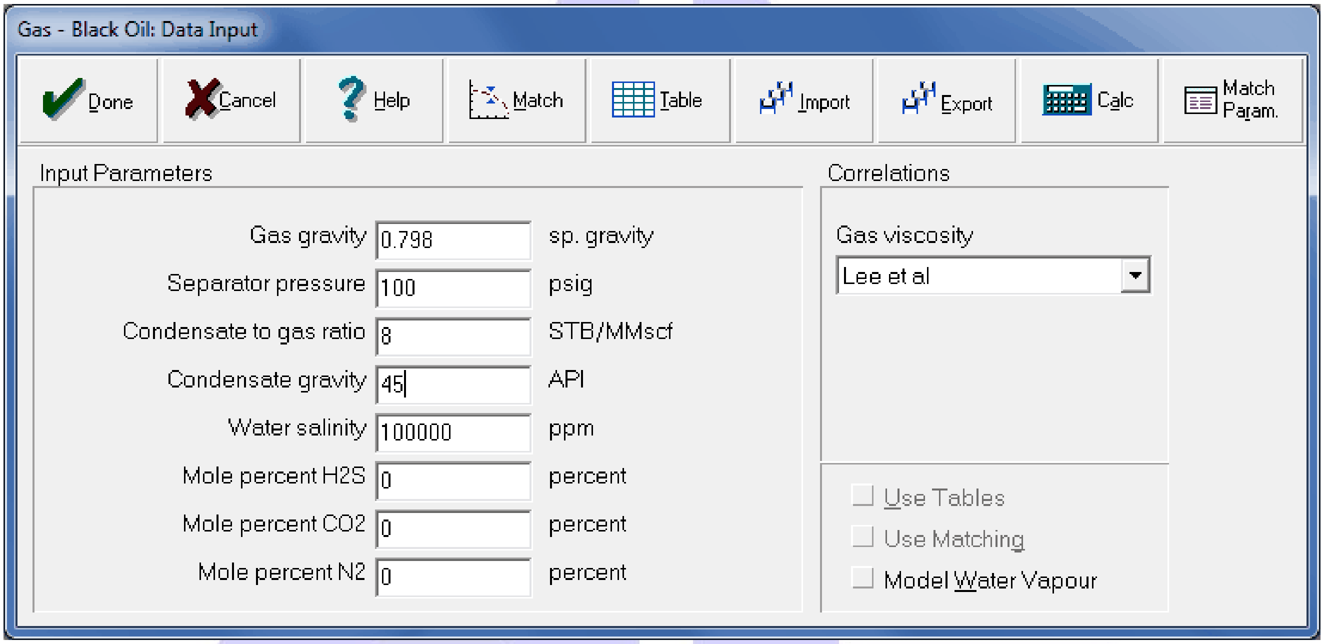
The depths entered here must match the depths entered in the reservoir pore volume versus depth table (see **Tank Data Input**). If a primary gas cap exists, the datum depth must be the depth of the initial Gas/Oil contact. The datum depth must correspond to the 0 pore volume versus depth and the bottom depth of the last layer must correspond to the 1 pore volume versus depth.

➲ **The datum depth defines the top of the top layer, so all layer bottom depths must be greater than the datum depth. MBAL will sort the layers in the table by the layer bottom depth. The definition of any layer less that one foot in thickness is not possible**

2.3.4.2.9 PVT for Gas

When gas is defined as the fluid type in the **Options** menu, the PVT dialogue box displayed below is observed.

The dry gas model assumes all liquid dropout occurs at the separator. In the calculations, an equivalent gas rate is used (based on the CGR entered) that allows for condensate production to ensure that a mass balance is observed.


Gas - Black Oil: Data Input
Done
Cancel
Help
Match
Table
Import
Export
Calc
Match Param.
Input Parameters
Correlations
☐ Use Tables
☐ Use Matching
☐ Model Water Vapour

Gas gravity 0.798 sp. gravity
Separator pressure 100 psig
Condensate to gas ratio 8 STB/MMscf
Condensate gravity 45 API
Water salinity 100000 ppm
Mole percent H2S 0 percent
Mole percent CO2 0 percent
Mole percent N2 0 percent

Gas viscosity: Lee et al

Enter the required fluid data in the fields provided.

Input Parameters

Gas gravity	This is defined as the ratio of the density of the gas to the density of the air both at standard conditions, equal to the ratio of the gas molecular weight to the air molecular weight
Separator pressure	This is used to convert the amount of condensate in an equivalent gas amount (see Gas Equivalent 460)
Condensate to gas ratio	This is the ratio of the volume of condensate to the volume of gas (both expressed as volumes at standard conditions) obtained by flashing the total fluid to standard conditions
Condensate gravity	This is the gravity of the condensate obtained by flashing the total fluid to standard conditions. The gravity is defined as ratio of the condensate density to the water density, both at standard conditions

Water salinity	Concentration of salts in water expressed in ppm equivalent
Mole % of CO_2, N_2 and H_2S	These represent the molar percent of the impurities in the gas stream separated at standard conditions

Input Fields

Correlations	Select the gas viscosity correlation to apply
Use Tables	Check the 'Use Tables' flag if the program is to use the measured PVT data supplied in the PVT tables. Parameters for which detailed PVT data is provided, MBAL will use these values instead of the correlations. Disallow (uncheck) this option, if it is decided to use the (matched or un-matched) black oil correlations instead of the PVT tables. This button will be disabled if no table data has been entered - click the 'Table' button to enter the table data
Use Matching	Check the 'Use Matching' box if it is desired to use the matched black oil correlations. Disallow (uncheck) this option, if it is decided to use the original unmatched black oil correlations. This button will be disabled if no matching data has been calculated - click the 'Matching' button to enter matching data and calculate matching parameters
Model Water Vapour	Check the 'Model Water Vapour' box if the water that can be vaporised in the gas is to be calculated. See Ref: "Properties of Petroleum Fluids 2nd Edition" Page 460

Multiple PVT Definitions

In some circumstances, the PVT section will allow the user to define more than one set of PVT data. Note that each set of PVT data includes the input PVT (e.g. GOR, API, gas gravity) as well as matching tables, matching parameters and table data. In these cases the above dialogues will look slightly different:

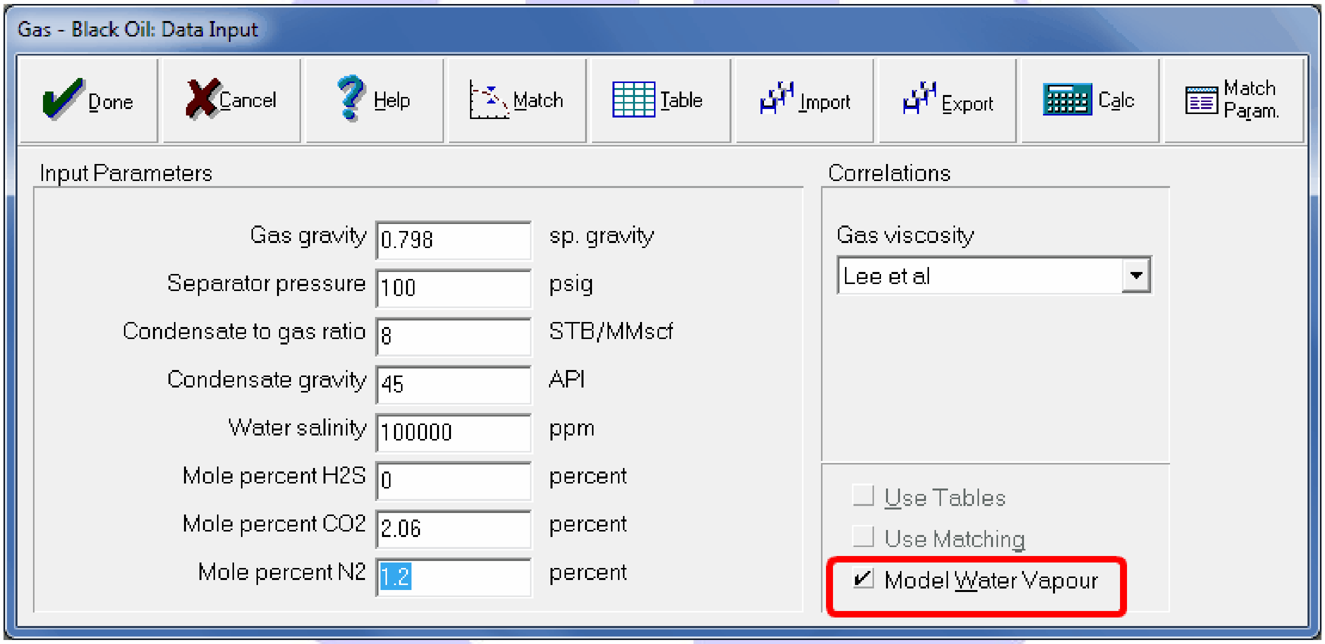
- All the currently defined sets of PVT data will be listed down the right hand side of the dialogue. Click on the PVT definition which is to be edited - all of the fields and the actions relating to the buttons will now act on the PVT definition selected.
- An extra field will be displayed at the top of the dialogue to allowing the name of the PVT definition to be altered.
- Three buttons are also displayed at the top of the dialogue. Click on the plus button to create a new empty PVT definition. Click on the minus button to delete the currently selected PVT definition. Click on the multiply button to create a new PVT definition which is a copy of the currently selected PVT definition.

Command Buttons

Match	Displays a variable entry dialogue box in which measured PVT laboratory data can be entered to modify the selected correlations so that they fit the measured data
Table	Displays a variable entry screen in which the user can enter or import detailed PVT laboratory data. This command works with the 'Use Tables' flag. When the option is checked, the program uses the measured data provided in the tables. If **MBAL** requires data not provided in the tables, it will calculate the necessary parameters using the selected correlation
Import	Displays a dialogue to allow selection of a **PROSPER** PVT file to import into **MBAL**
Calc	Displays a dialogue box where calculations on PVT parameters are performed using the current PVT model. This can be used to verify the consistency of the PVT data entered
Match Param	Displays a dialogue to view or edit the current matching parameters

2.3.4.2.10 Water Vapour Option

The “Model Water Vapour” option is available for gas reservoirs and serves in providing the amount of water (from the vaporised water) that will drop out as pressure depletes in the reservoir.

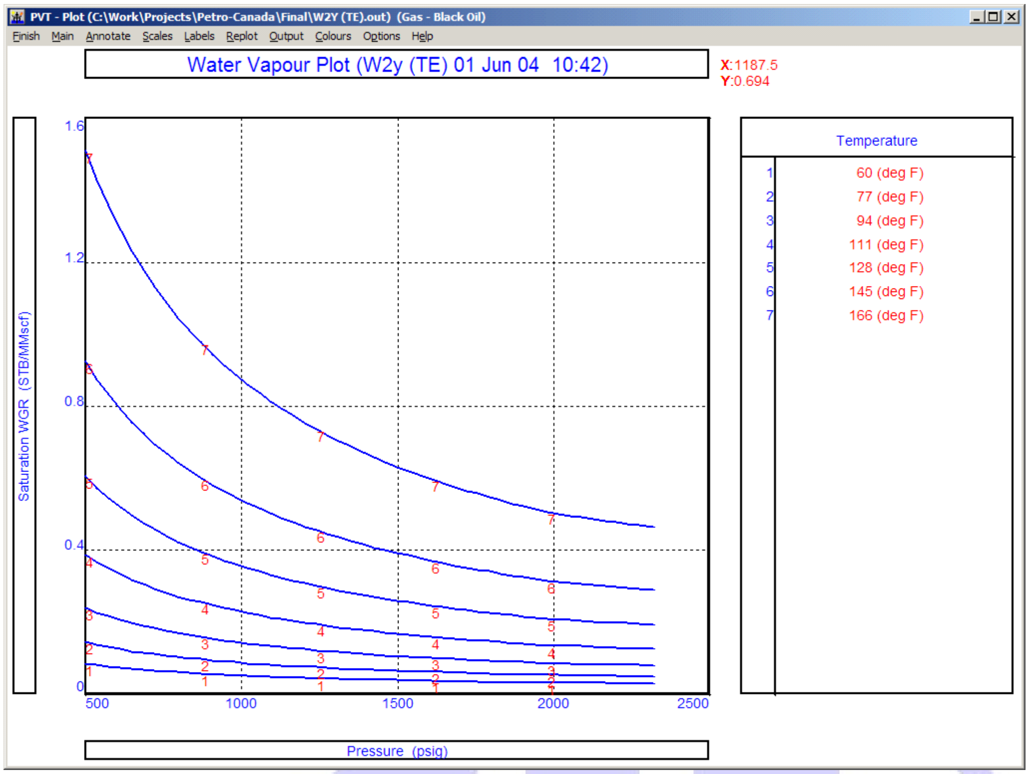


Gas gravity 0.798 sp. gravity
Separator pressure 100 psig
Condensate to gas ratio 8 STB/MMscf
Condensate gravity 45 API
Water salinity 100000 ppm
Mole percent H2S 0 percent
Mole percent CO2 2.06 percent
Mole percent N2 1.2 percent

Gas viscosity Lee et al

☐ Use Tables
☐ Use Matching
☑ Model Water Vapour

The following plot is taken from **PROSPER** and shows the vaporised water curves used by the program when this option is activated:


PVT - Plot (C:\Work\Projects\Petro-Canada\Final\W2Y (TE).out) (Gas - Black Oil)
Finish
Main
Annotate
Scales
Labels
Replot
Output
Colours
Options
Help
Water Vapour Plot (W2y (TE) 01 Jun 04 10:42)
X:1187.5
Y:0.694
Saturation WGR (STB/MMscf)
1.6
1.2
0.8
0.4
0
500
1000
1500
2000
2500
Pressure (psig)
Temperature
1 60 (deg F)
2 77 (deg F)
3 94 (deg F)
4 111 (deg F)
5 128 (deg F)
6 145 (deg F)
7 166 (deg F)

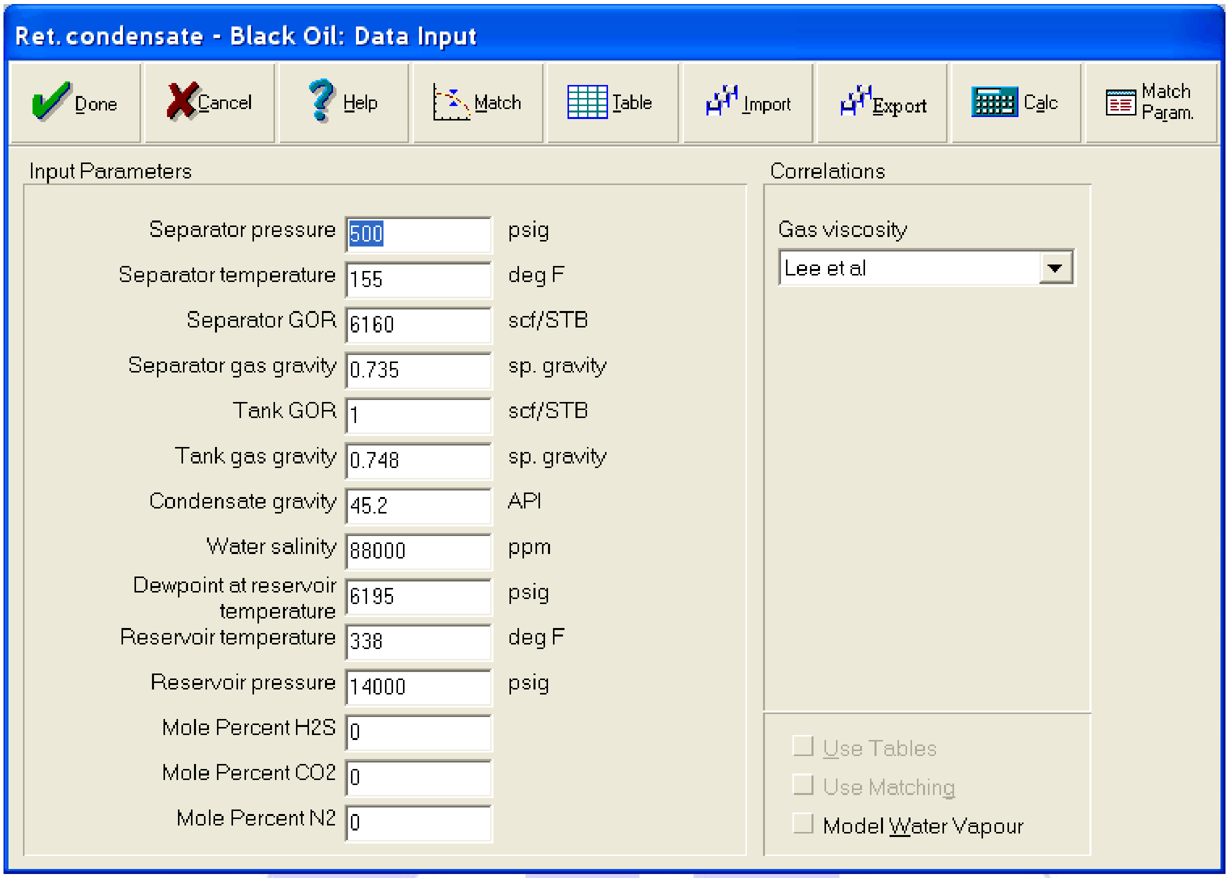
Previous tests have shown that little impact is made on material balance calculations with the application of condensed water effects (it would however, impact on the thermodynamic properties of the fluid.). However, when a reservoir is used as part of an **IPM** model, then this water will cause well loading for low rates and will result in the well dying sooner in the prediction (more realistic forecast); hence it is important to have this parameter calculated at reservoir level and provided to the well models as well as being used for material balance.

The properties of gas (Z factor, density etc) will be calculated with the gas equation of state PV = ZnRT and the Standing-Katz model with corrections for impurities.

As with the black oil model for oils, the PVT properties can be matched using the same procedure.

2.3.4.2.11 PVT for Retrograde Condensate

If 'Retrograde Condensate' is defined as the fluid type in the **Options** menu, the following PVT dialogue box is displayed:


Ret.condensate - Black Oil: Data Input
Done
Cancel
Help
Match
Table
Import
Export
Calc
Match Param.
Input Parameters
Correlations

Separator pressure	500	psig
Separator temperature	155	deg F
Separator GOR	6160	scf/STB
Separator gas gravity	0.735	sp. gravity
Tank GOR	1	scf/STB
Tank gas gravity	0.748	sp. gravity
Condensate gravity	45.2	API
Water salinity	88000	ppm
Dewpoint at reservoir temperature	6195	psig
Reservoir temperature	338	deg F
Reservoir pressure	14000	psig
Mole Percent H2S	0	
Mole Percent CO2	0	
Mole Percent N2	0	

Gas viscosity: Lee et al

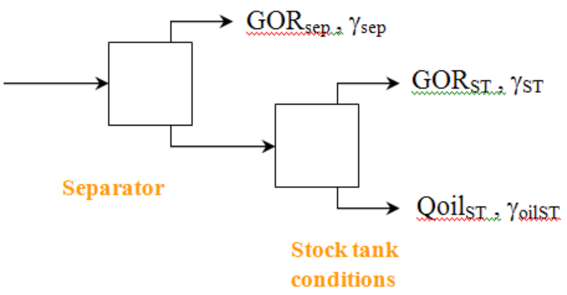
☐ Use Tables
☐ Use Matching
☐ Model Water Vapour

Enter the required fluid data in the fields provided.

Input Parameters

These are the basic input data required by the black oil model in form of gas gravity, oil gravity and GOR (or CGR), which are determined by flashing the fluid down to standard conditions through separator train. This train defines the "path" to standard conditions used to express the standard volumes (rates).

The meaning of the PVT input properties for a black oil model is illustrated in the following figure and in the comments below:


GOR$_{sep}$, γ_{sep}
GOR$_{ST}$, γ_{ST}
Qoil$_{ST}$, γ_{oilST}
Separator
Stock tank
conditions

Where:

γ_i = specific gas gravities

γ_{oilST} = oil gravity

GOR_i=(Volume of gas @ STD at stage i) / $Qoil_{ST}$

Total GOR: $GOR_{tot} = GOR_{sep} + GOR_{ST}$

The average specific gravity is given by:

$$\gamma_g = \sum_i \frac{GOR_i \cdot \gamma_i}{GOR_{tot}} = \frac{GOR_{sep} \cdot \gamma_{sep} + GOR_{ST} \cdot \gamma_{ST}}{GOR_{tot}}$$

The oil gravity is by definition the ratio between the density of the oil and the water both at STD.

The impurities correspond to the mole % of CO2, N2 and H2S in the gas liberated in the process shown above.

The formula above can be used to reduce a train of n separators to an equivalent one stage.

Gas gravity	This is defined as the ratio of the density of the gas to the density of the air both at standard conditions, equal to the ratio of the gas molecular weight to the air molecular weight
Gas to oil ratio	This is the ratio of the volume of gas liberated at each stage to the volume of oil at the last stage (both expressed as volumes at standard conditions) obtained by flashing the total fluid to standard conditions through the separator train above
Condensate gravity	This is the gravity of the condensate at the last stage obtained by flashing the total fluid to standard conditions. The gravity is defined as ratio of the condensate density to the water density, both at standard conditions
Water salinity	Concentration of salts in water expressed in ppm equivalent
Mole % of CO_2, N_2 and H_2S	These represent the molar percent of the impurities in the gas stream separated at standard conditions

If Tank GOR and Tank gas Gravity are unknown, they may be left at zero. If this is the case, then the Total produced GOR should be entered under 'Separator GOR'

Input Fields

Correlations	Select the gas viscosity correlation to apply
Use Tables	Check the 'Use Tables' flag if the program is to use the measured PVT data supplied in the PVT tables. In parameters where detailed PVT data is provided, MBAL will use these values instead of the correlations. Disallow (uncheck) this option, if it is decided to use the (matched or un-matched) black oil correlations instead of the PVT tables. This button will be disabled if no table data has been entered - click the Table button to enter the table data
Use Matching	Check the 'Use Matching' box if it is desired to use the matched black oil correlations. Disallow (uncheck) this option, if it is decided to use the original unmatched black oil correlations. This button will be disabled if no matching data has been calculated - click the Matching button to enter matching data and calculate matching parameters
Model Water Vapour	Check the 'Model Water Vapour' box if the water that can be vaporised in the gas is to be calculated. See Ref: "Properties of Petroleum Fluids 2nd Edition" Page 460

Important Note

The black oil model for gas retrograde condensate is a mathematical model developed by *Petroleum Experts* based on mass balance. As it relies on black oil assumptions (which assumes the quality of gas and oil to be invariant), it requires to be validated 110 against an Equation of State model before it can reliably used

Multiple PVT Definitions

In some circumstances, the PVT section will allow the user to define more than one set of PVT data. Note that each set of PVT data includes the input PVT (e.g. GOR, API, gas gravity) as well as matching tables, matching parameters and table data. In these cases the above dialogues will look slightly different:

- All the currently defined sets of PVT data will be listed down the right hand side of the dialogue. Click on the PVT definition which is to be edited - all of the fields and the actions relating to the buttons will now act on the PVT definition selected.
- An extra field will be displayed at the top of the dialogue to allowing the name of the PVT definition to be altered.

- Three buttons are also displayed at the top of the dialogue. Click on the plus button to create a new empty PVT definition. Click on the minus button to delete the currently selected PVT definition. Click on the multiply button to create a new PVT definition which is a copy of the currently selected PVT definition.

Command Buttons

Match	Displays a variable entry dialogue box in which measured PVT laboratory data can be entered to modify the selected correlations so that they fit the measured data
Table	Displays a variable entry screen in which the user can enter or import detailed PVT laboratory data. This command works with the 'Use Tables' flag. When the option is checked, the program uses the measured data provided in the tables. If **MBAL** requires data not provided in the tables, it will calculate the necessary parameters using the selected correlation
Import	Displays a dialogue to allow selection of a **PROSPER** PVT file to import into **MBAL**
Calc	Displays a dialogue box where calculations on PVT parameters are performed using the current PVT model. This can be used to verify the consistency of the PVT data entered
Match Param	Displays a dialogue to view or edit the current matching parameters

2.3.4.2.12 Black Oil Condensate model validation procedure

The formulation of the Black Oil model for condensates is described in the **PROSPER** manual and it can be used to model the majority of condensates. The shape of the CGR curve is difficult to predict from the basic data and this is why condensate models need to be validated before use.

Within **MBAL**,the condensate model needs to be matched to CCE data (honouring mass balance). The process that **MBAL** will follow is one of depletion by removing gas from the reservoir, which resembles a depletion experiment.

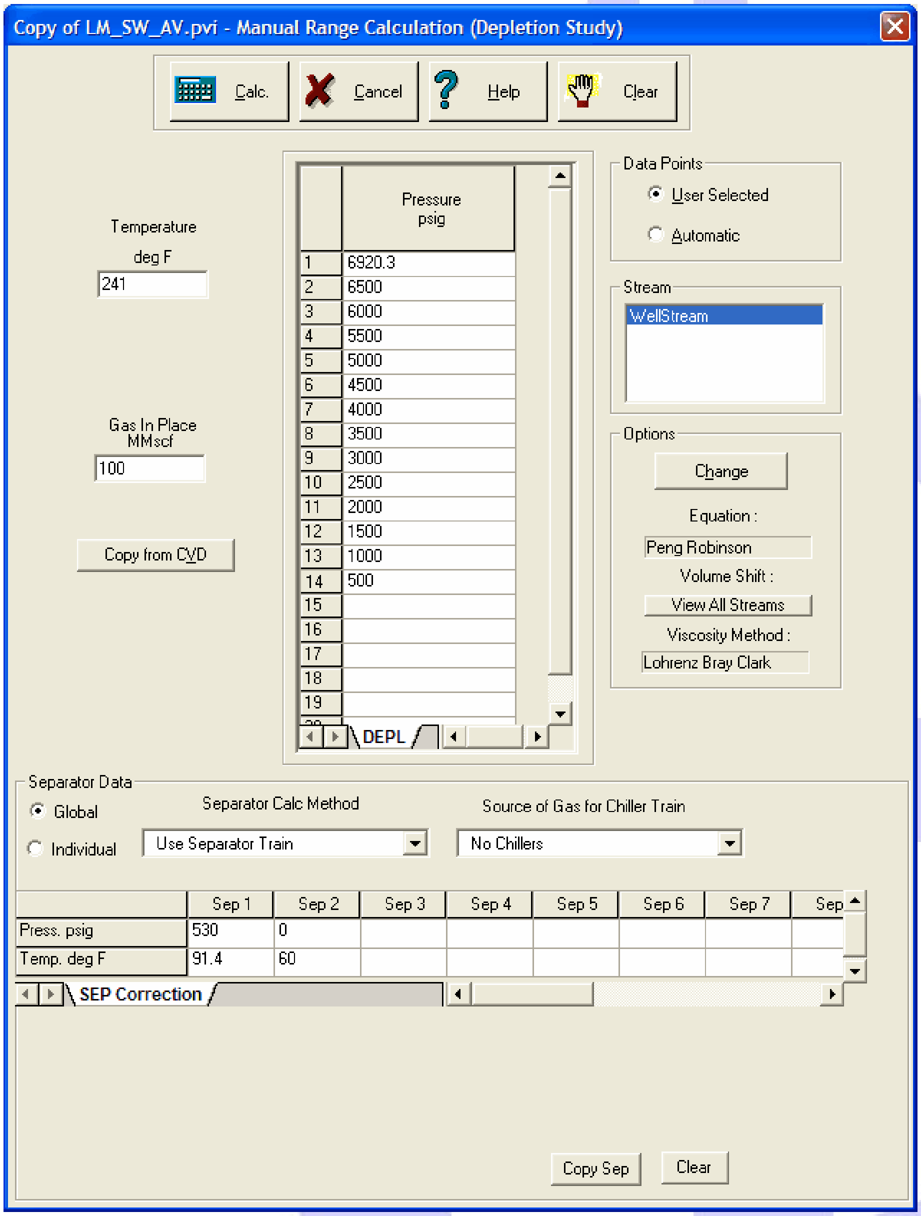
The objective of the validation procedure is *to cross check that the BLACK OIL model reasonably reproduces the drop out and recovery results as predicted by laboratory experiments and/or fully compositional models*.

.To perform the validation, the following steps are taken:

1. Use an Equation of State (EOS) package (e.g. **PVTP**) to characterise a fluid compositionally. Characterisation of a fluid indicates that the properties predicted using the Equation of State have been confirmed against those that have been measured in the laboratory. It is assumed that the fluid characterisation has already been performed in a fluid characterisation package such as PVTP. For further information on how to characterise a fluid, standard examples can be found in the PVTP user guide with a step by step guide towards the

characterisation.

2. Using this characterised fluid in PVTP, simulate a depletion experiment using the given separation scheme and an initial gas in place of 100 MMSCF. The range of pressure values used may start from the reservoir pressure and reduce at regular intervals. In the example below, a pressure value at every 500 psig is used.


Copy of LM_SW_AV.pvi - Manual Range Calculation (Depletion Study)
Calc.
Cancel
Help
Clear
Copy from CVD
Data Points
Stream
Options
Change
Separator Data
Copy Sep
Clear

Temperature deg F: 241

Gas In Place MMscf: 100

	Pressure psig
1	6920.3
2	6500
3	6000
4	5500
5	5000
6	4500
7	4000
8	3500
9	3000
10	2500
11	2000
12	1500
13	1000
14	500
15	
16	
17	
18	
19	

DEPL

Data Points: ● User Selected ○ Automatic

Stream: WellStream

Equation : Peng Robinson

Volume Shift : View All Streams

Viscosity Method : Lohrenz Bray Clark

Separator Data: ● Global ○ Individual

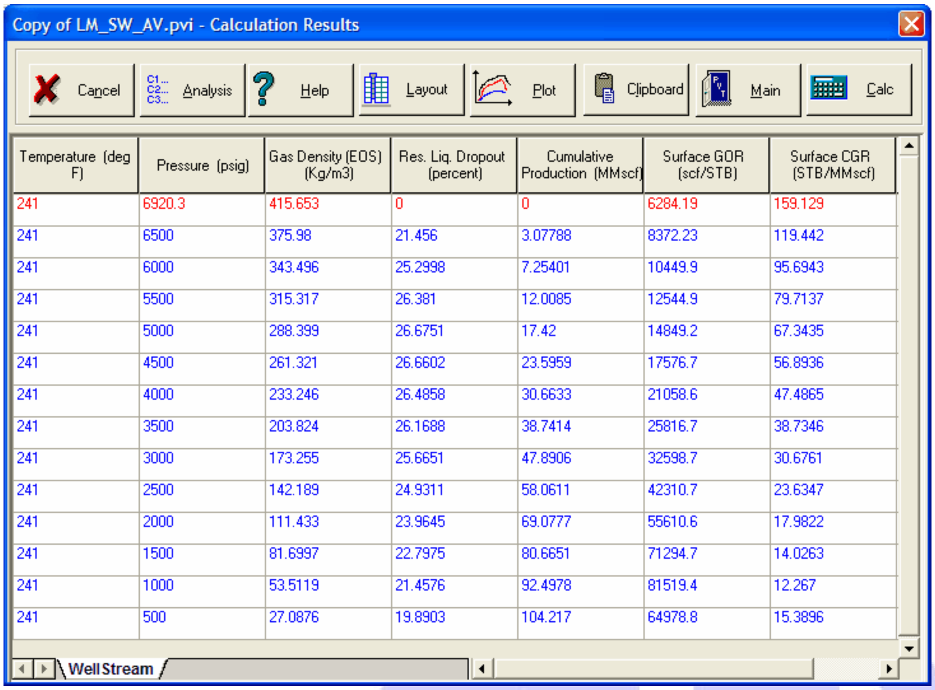
Separator Calc Method: Use Separator Train

Source of Gas for Chiller Train: No Chillers

	Sep 1	Sep 2	Sep 3	Sep 4	Sep 5	Sep 6	Sep 7	Sep
Press. psig	530	0						
Temp. deg F	91.4	60						

SEP Correction

As soon as the calculations are finished:

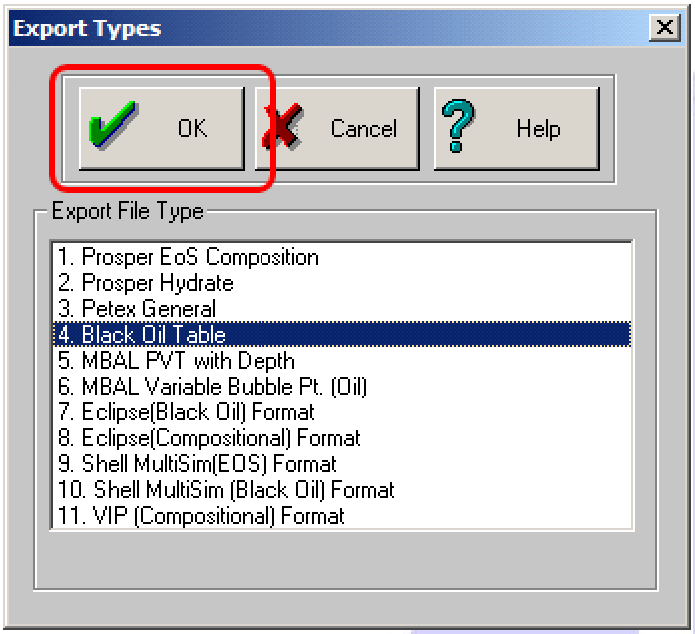


Temperature (deg F)	Pressure (psig)	Gas Density (EOS) (Kg/m3)	Res. Liq. Dropout (percent)	Cumulative Production (MMscf)	Surface GOR (scf/STB)	Surface CGR (STB/MMscf)
241	6920.3	415.653	0	0	6284.19	159.129
241	6500	375.98	21.456	3.07788	8372.23	119.442
241	6000	343.496	25.2998	7.25401	10449.9	95.6943
241	5500	315.317	26.381	12.0085	12544.9	79.7137
241	5000	288.399	26.6751	17.42	14849.2	67.3435
241	4500	261.321	26.6602	23.5959	17576.7	56.8936
241	4000	233.246	26.4858	30.6633	21058.6	47.4865
241	3500	203.824	26.1688	38.7414	25816.7	38.7346
241	3000	173.255	25.6651	47.8906	32598.7	30.6761
241	2500	142.189	24.9311	58.0611	42310.7	23.6347
241	2000	111.433	23.9645	69.0777	55610.6	17.9822
241	1500	81.6997	22.7975	80.6651	71294.7	14.0263
241	1000	53.5119	21.4576	92.4978	81519.4	12.267
241	500	27.0876	19.8903	104.217	64978.8	15.3896

3. As soon as the calculations are finished, transfer the following results to a package like EXCEL

    i) Produced GOR i.e. yield
    ii) Liquid Drop Out
    iii) Gas recovery

4. Simulate a 'Constant Composition Experiment' (CCE) with the compositional tool (**PVTP**) and create an export file with the match data **MBAL** will need to match the BO model to:



Export File Type

1. Prosper EoS Composition
2. Prosper Hydrate
3. Petex General
4. Black Oil Table
5. MBAL PVT with Depth
6. MBAL Variable Bubble Pt. (Oil)
7. Eclipse(Black Oil) Format
8. Eclipse(Compositional) Format
9. Shell MultiSim(EOS) Format
10. Shell MultiSim (Black Oil) Format
11. VIP (Compositional) Format

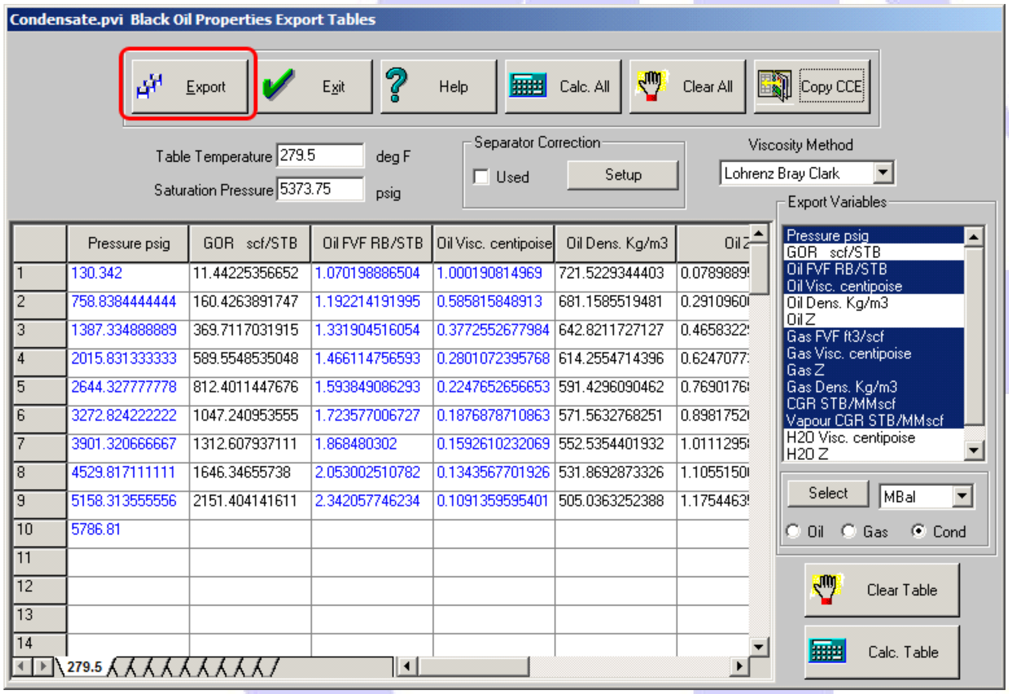


Table Temperature 279.5 deg F

Saturation Pressure 5373.75 psig

Separator Correction: ☐ Used

Viscosity Method: Lohrenz Bray Clark

	Pressure psig	GOR scf/STB	Oil FVF RB/STB	Oil Visc. centipoise	Oil Dens. Kg/m3	Oil Z
1	130.342	11.44225356652	1.070198886504	1.000190814969	721.5229344403	0.0789889
2	758.8384444444	160.4263891747	1.192214191995	0.585815848913	681.1585519481	0.2910960
3	1387.334888889	369.7117031915	1.331904516054	0.3772552677984	642.8211727127	0.4658322
4	2015.831333333	589.5548535048	1.466114756593	0.2801072395768	614.2554714396	0.6247077
5	2644.327777778	812.4011447676	1.593849086293	0.2247652656653	591.4296090462	0.7690176
6	3272.824222222	1047.240953555	1.723577006727	0.1876878710863	571.5632768251	0.8981752
7	3901.320666667	1312.607937111	1.868480302	0.1592610232069	552.5354401932	1.0111295
8	4529.817111111	1646.34655738	2.053002510782	0.1343567701926	531.8692873326	1.1055150
9	5158.313555556	2151.404141611	2.342057746234	0.1091359595401	505.0363252388	1.1754463
10	5786.81					
11						
12						
13						
14						

279.5

Export Variables

- Pressure psig
- GOR scf/STB
- Oil FVF RB/STB
- Oil Visc. centipoise
- Oil Dens. Kg/m3
- Oil Z
- Gas FVF ft3/scf
- Gas Visc. centipoise
- Gas Z
- Gas Dens. Kg/m3
- CGR STB/MMscf
- Vapour CGR STB/MMscf
- H20 Visc. centipoise
- H20 Z

MBal

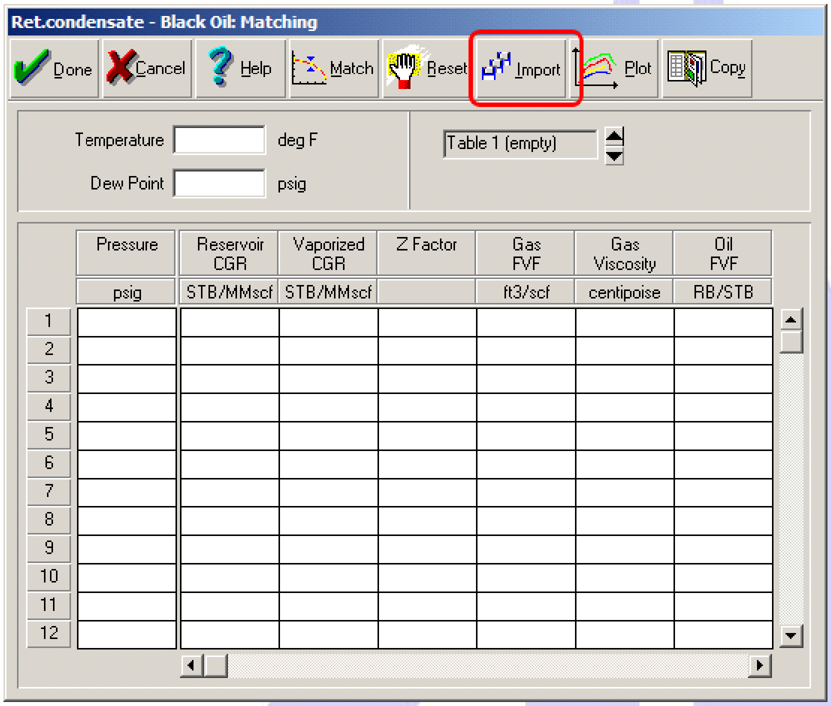
○ Oil ○ Gas ● Cond

It should be noted that **MBAL** requires the gas Z-factor from the CCE.
As **MBAL** uses a PVT model which accounts for the condensate dropout, there is no need to modify the Z factor for liquid.

At this point, export and save the .ptb file.

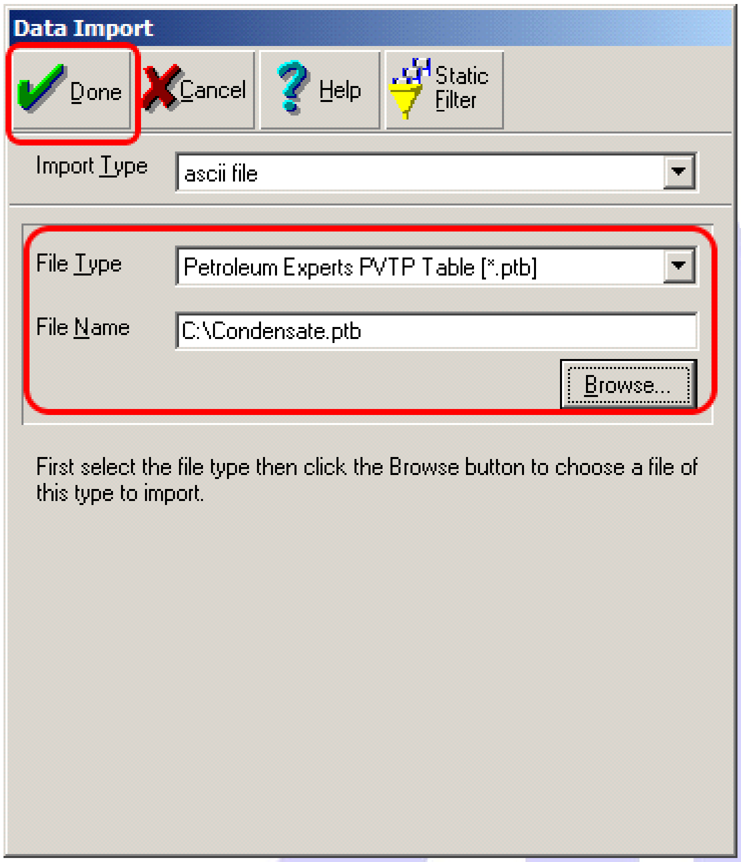
5. Go to **MBAL** PVT section and enter the separator data and dew point under the PVT input section as shown earlier.

6. Transfer the drop out and gas property data generated with CCE to the match data in PVT screens of **MBAL**. Perform the match, so that the black oil model is tuned.



Ret.condensate - Black Oil: Matching
Done
Cancel
Help
Match
Reset
Import
Plot
Copy
Temperature
deg F
Dew Point
psig
Table 1 (empty)

	Pressure	Reservoir CGR	Vaporized CGR	Z Factor	Gas FVF	Gas Viscosity	Oil FVF
	psig	STB/MMscf	STB/MMscf		ft3/scf	centipoise	RB/STB
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							

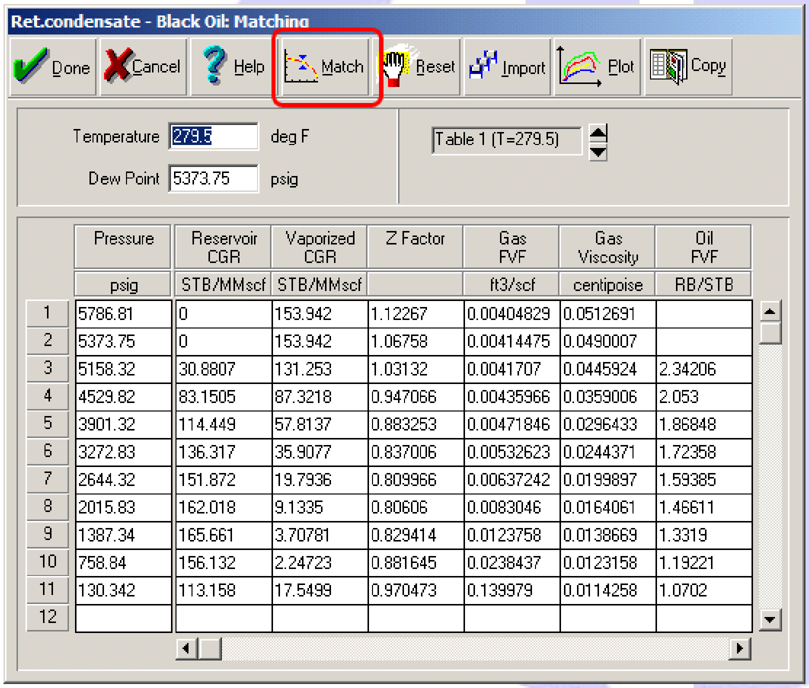

Data Import
Done
Cancel
Help
Static Filter
Browse...

Import Type: ascii file

File Type: Petroleum Experts PVTP Table [*.ptb]

File Name: C:\Condensate.ptb

First select the file type then click the Browse button to choose a file of this type to import.

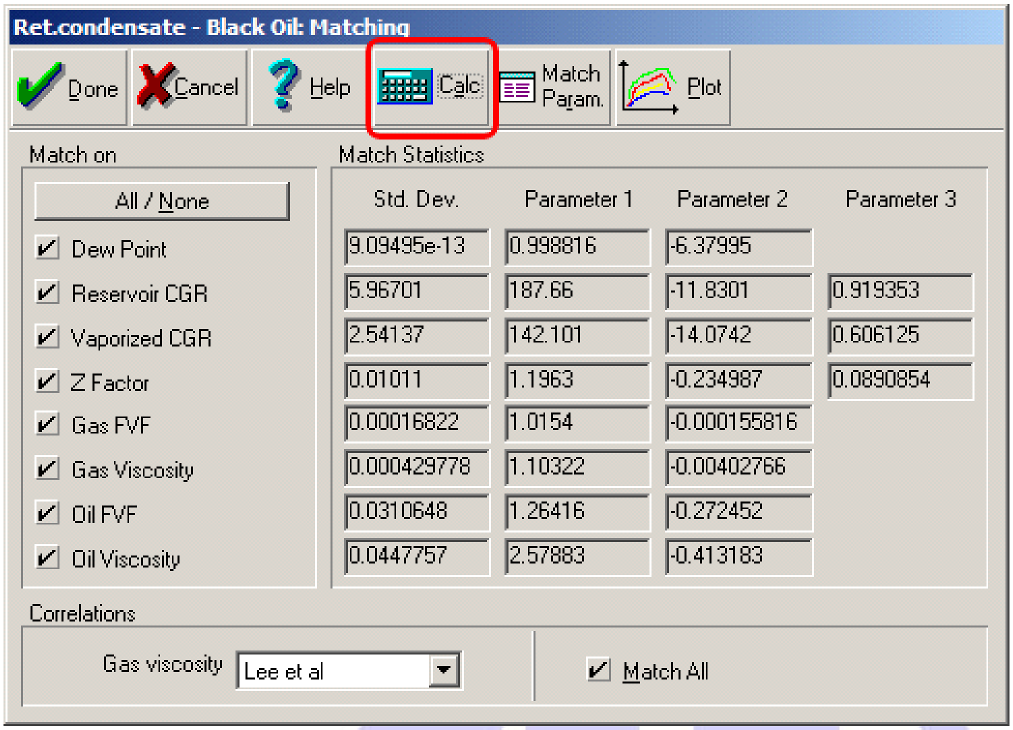

Ret.condensate - Black Oil: Matching
Done
Cancel
Help
Match
Reset
Import
Plot
Copy

Temperature: 279.5 deg F

Dew Point: 5373.75 psig

Table 1 (T=279.5)

	Pressure	Reservoir CGR	Vaporized CGR	Z Factor	Gas FVF	Gas Viscosity	Oil FVF
	psig	STB/MMscf	STB/MMscf		ft3/scf	centipoise	RB/STB
1	5786.81	0	153.942	1.12267	0.00404829	0.0512691	
2	5373.75	0	153.942	1.06758	0.00414475	0.0490007	
3	5158.32	30.8807	131.253	1.03132	0.0041707	0.0445924	2.34206
4	4529.82	83.1505	87.3218	0.947066	0.00435966	0.0359006	2.053
5	3901.32	114.449	57.8137	0.883253	0.00471846	0.0296433	1.86848
6	3272.83	136.317	35.9077	0.837006	0.00532623	0.0244371	1.72358
7	2644.32	151.872	19.7936	0.809966	0.00637242	0.0199897	1.59385
8	2015.83	162.018	9.1335	0.80606	0.0083046	0.0164061	1.46611
9	1387.34	165.661	3.70781	0.829414	0.0123758	0.0138669	1.3319
10	758.84	156.132	2.24723	0.881645	0.0238437	0.0123158	1.19221
11	130.342	113.158	17.5499	0.970473	0.139979	0.0114258	1.0702
12							

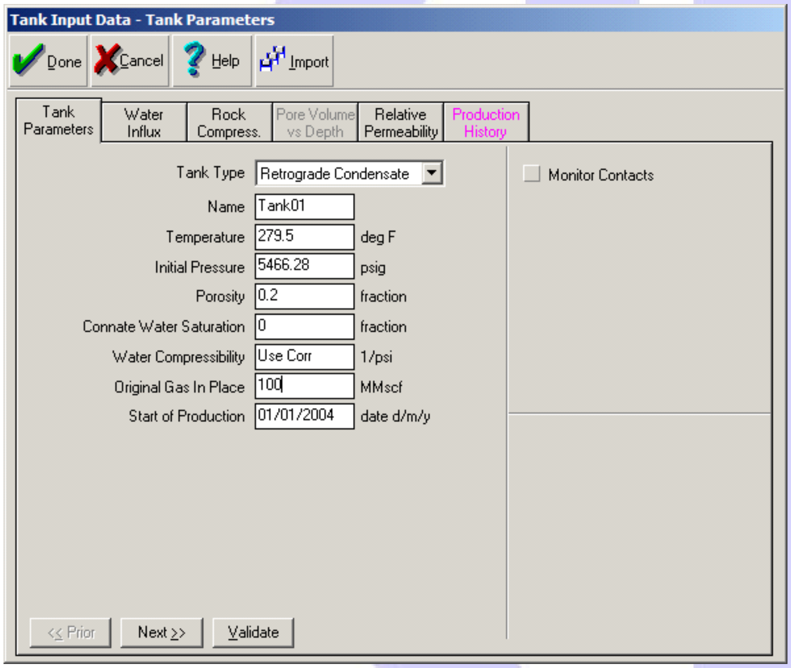

Ret.condensate - Black Oil: Matching
Done
Cancel
Help
Calc
Match Param.
Plot
Match on
All / None
Match Statistics
Correlations

Match on	Std. Dev.	Parameter 1	Parameter 2	Parameter 3
☑ Dew Point	9.09495e-13	0.998816	-6.37995	
☑ Reservoir CGR	5.96701	187.66	-11.8301	0.919353
☑ Vaporized CGR	2.54137	142.101	-14.0742	0.606125
☑ Z Factor	0.01011	1.1963	-0.234987	0.0890854
☑ Gas FVF	0.00016822	1.0154	-0.000155816	
☑ Gas Viscosity	0.000429778	1.10322	-0.00402766	
☑ Oil FVF	0.0310648	1.26416	-0.272452	
☑ Oil Viscosity	0.0447757	2.57883	-0.413183	

Gas viscosity: Lee et al

☑ Match All

7. Under **Tank | Input Data** and specify the GIIP of 100 MMSCF and set the connate water saturation in the tank to zero:


Tank Input Data - Tank Parameters
Done
Cancel
Help
Import
Tank Parameters
Water Influx
Rock Compress.
Pore Volume vs Depth
Relative Permeability
Production History
<< Prior
Next >>
Validate

Tank Type: Retrograde Condensate

Name: Tank01

Temperature: 279.5 deg F

Initial Pressure: 5466.28 psig

Porosity: 0.2 fraction

Connate Water Saturation: 0 fraction

Water Compressibility: Use Corr 1/psi

Original Gas In Place: 100 MMscf

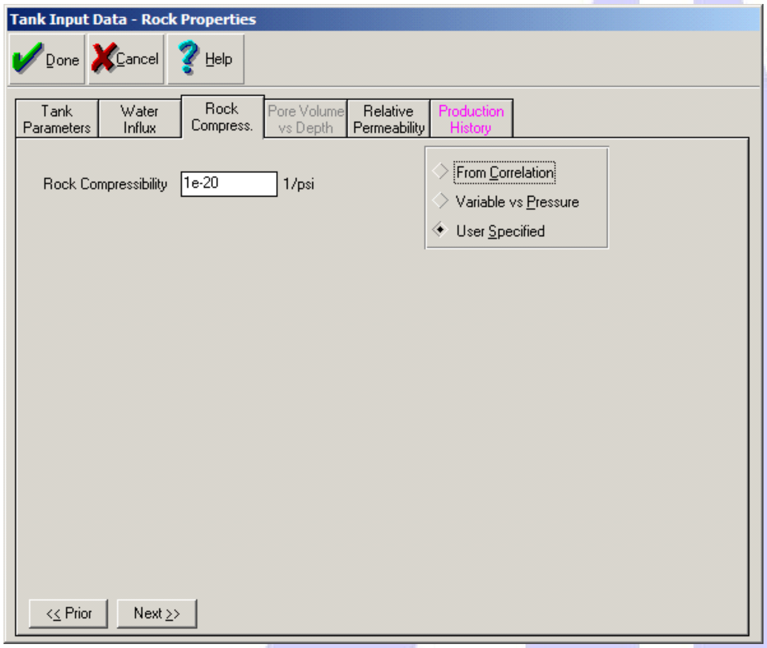
Start of Production: 01/01/2004 date d/m/y

☐ Monitor Contacts

This will ensure that no support comes from connate water expansion and the gas in place is the same as the depletion experiment in **PVTP** (since we want to compare the two).

8. Set water influx to 'None'.

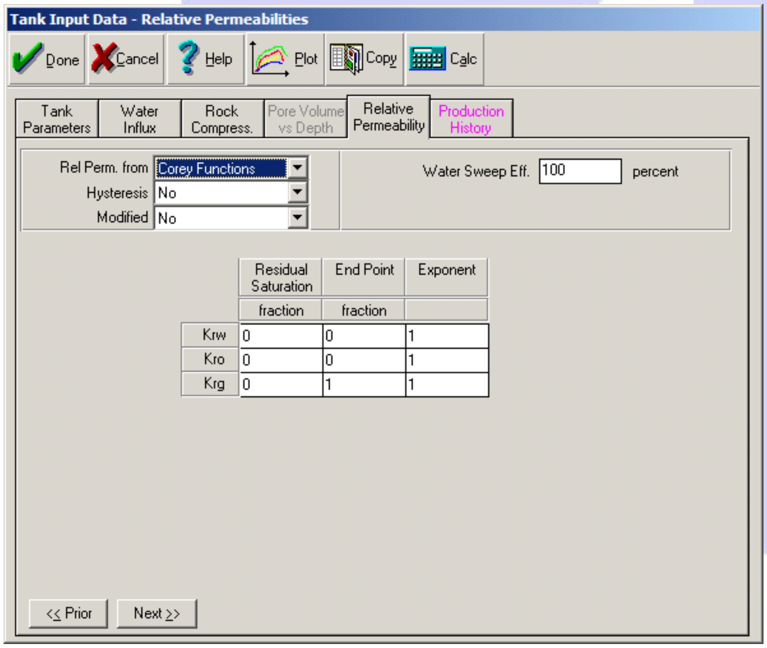
9. Set the tank rock compressibility to 1E-20, i.e. no energy will come from the rock itself.


Tank Input Data - Rock Properties
Done
Cancel
Help
Tank Parameters
Water Influx
Rock Compress.
Pore Volume vs Depth
Relative Permeability
Production History
From Correlation
Variable vs Pressure
User Specified
<< Prior
Next >>

Rock Compressibility 1e-20 1/psi

○ From Correlation
○ Variable vs Pressure
● User Specified

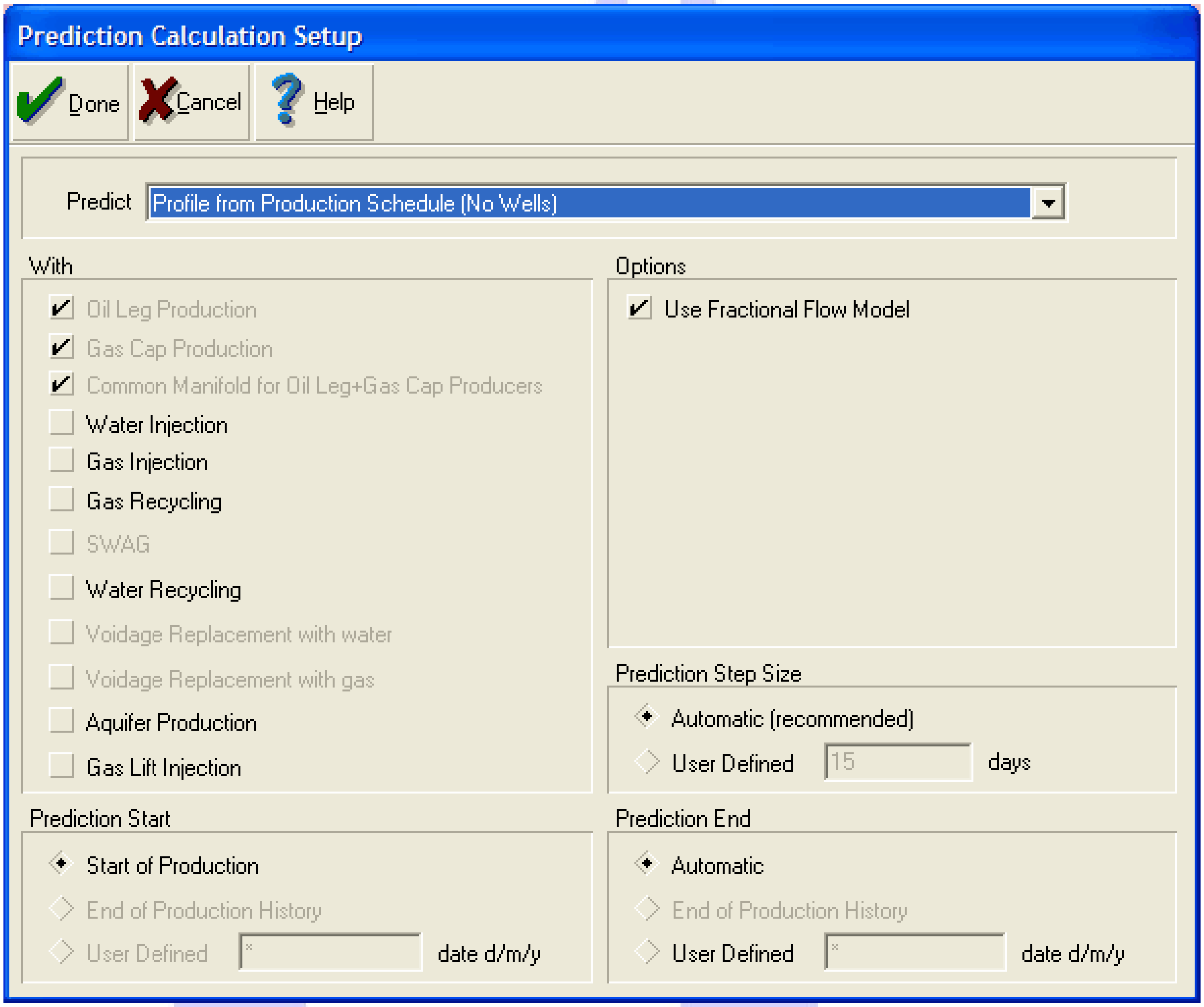
10. Set the relative permeability in such a manner that oil is blocked, i.e. oil relative permeability is zero:


Tank Input Data - Relative Permeabilities
Done
Cancel
Help
Plot
Copy
Calc
Tank Parameters
Water Influx
Rock Compress.
Pore Volume vs Depth
Relative Permeability
Production History
<< Prior
Next >>

Rel Perm. from Corey Functions
Hysteresis No
Modified No
Water Sweep Eff. 100 percent

	Residual Saturation	End Point	Exponent
	fraction	fraction	
Krw	0	0	1
Kro	0	0	1
Krg	0	1	1

11. Go to **Prediction | Prediction Setup** and set the model to ***"Profile from Production Schedule (No Wells)"*** and ensuring that the "Use Fractional Flow Model" has been selected.



Predict: Profile from Production Schedule (No Wells)

With
☑ Oil Leg Production
☑ Gas Cap Production
☑ Common Manifold for Oil Leg+Gas Cap Producers
☐ Water Injection
☐ Gas Injection
☐ Gas Recycling
☐ SWAG
☐ Water Recycling
☐ Voidage Replacement with water
☐ Voidage Replacement with gas
☐ Aquifer Production
☐ Gas Lift Injection

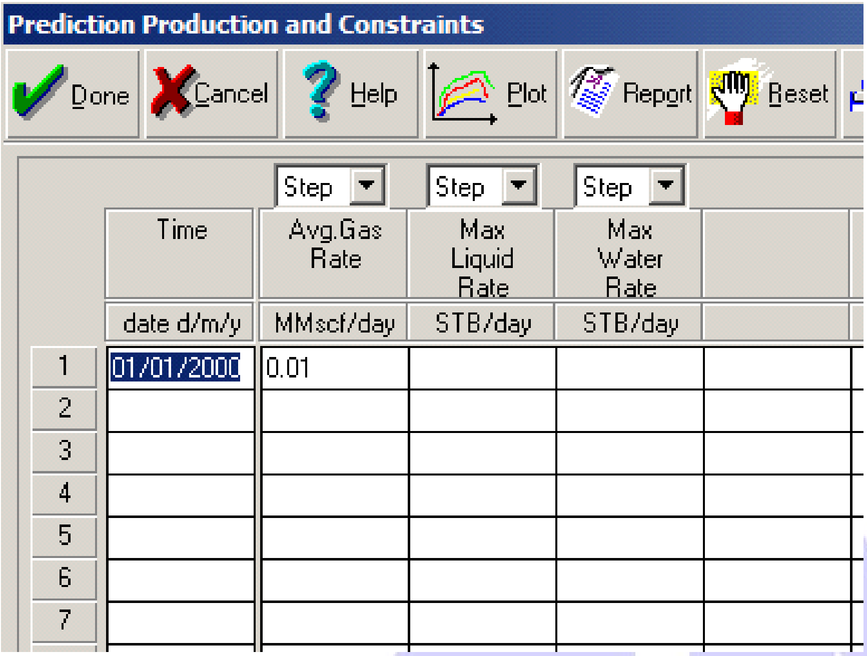
Options
☑ Use Fractional Flow Model

Prediction Step Size
● Automatic (recommended)
○ User Defined 15 days

Prediction Start
● Start of Production
○ End of Production History
○ User Defined date d/m/y

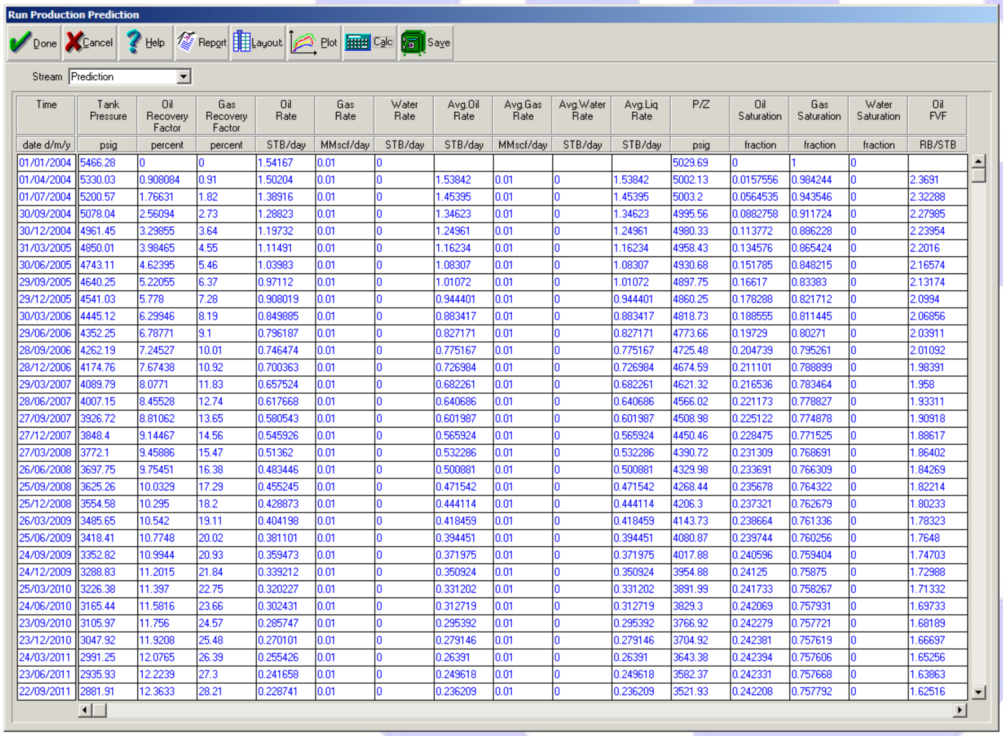
Prediction End
● Automatic
○ End of Production History
○ User Defined date d/m/y

12. In **Prediction | Production and Constraints** set the average gas production rate to a very small value as shown:



	Time	Avg.Gas Rate	Max Liquid Rate	Max Water Rate
	date d/m/y	MMscf/day	STB/day	STB/day
1	01/01/2000	0.01		
2				
3				
4				
5				
6				
7				

13. Run the prediction and save the model.



Stream: Prediction

Time	Tank Pressure	Oil Recovery Factor	Gas Recovery Factor	Oil Rate	Gas Rate	Water Rate	Avg.Oil Rate	Avg.Gas Rate	Avg.Water Rate	Avg.Liq Rate	P/Z	Oil Saturation	Gas Saturation	Water Saturation	Oil FVF
date d/m/y	psig	percent	percent	STB/day	MMscf/day	STB/day	STB/day	MMscf/day	STB/day	STB/day	psig	fraction	fraction	fraction	RB/STB
01/01/2004	5466.28	0	0	1.54167	0.01	0					5029.69	0	1	0	
01/04/2004	5330.03	0.908084	0.91	1.50204	0.01	0	1.53842	0.01	0	1.53842	5002.13	0.0157556	0.984244	0	2.3691
01/07/2004	5200.57	1.76631	1.82	1.38916	0.01	0	1.45395	0.01	0	1.45395	5003.2	0.0564535	0.943546	0	2.32288
30/09/2004	5078.04	2.56094	2.73	1.28823	0.01	0	1.34623	0.01	0	1.34623	4995.56	0.0882758	0.911724	0	2.27985
30/12/2004	4961.45	3.29855	3.64	1.19732	0.01	0	1.24961	0.01	0	1.24961	4980.33	0.113772	0.886228	0	2.23954
31/03/2005	4850.01	3.98465	4.55	1.11491	0.01	0	1.16234	0.01	0	1.16234	4958.43	0.134576	0.865424	0	2.2016
30/06/2005	4743.11	4.62395	5.46	1.03983	0.01	0	1.08307	0.01	0	1.08307	4930.68	0.151785	0.848215	0	2.16574
29/09/2005	4640.25	5.22055	6.37	0.97112	0.01	0	1.01072	0.01	0	1.01072	4897.75	0.16617	0.83383	0	2.13174
29/12/2005	4541.03	5.778	7.28	0.908019	0.01	0	0.944401	0.01	0	0.944401	4860.25	0.178288	0.821712	0	2.0994
30/03/2006	4445.12	6.29946	8.19	0.849885	0.01	0	0.883417	0.01	0	0.883417	4818.73	0.188555	0.811445	0	2.06856
29/06/2006	4352.25	6.78771	9.1	0.796187	0.01	0	0.827171	0.01	0	0.827171	4773.66	0.19729	0.80271	0	2.03911
28/09/2006	4262.19	7.24527	10.01	0.746474	0.01	0	0.775167	0.01	0	0.775167	4725.48	0.204739	0.795261	0	2.01092
28/12/2006	4174.76	7.67438	10.92	0.700363	0.01	0	0.726984	0.01	0	0.726984	4674.59	0.211101	0.788899	0	1.98391
29/03/2007	4089.79	8.0771	11.83	0.657524	0.01	0	0.682261	0.01	0	0.682261	4621.32	0.216536	0.783464	0	1.958
28/06/2007	4007.15	8.45528	12.74	0.617668	0.01	0	0.640686	0.01	0	0.640686	4566.02	0.221173	0.778827	0	1.93311
27/09/2007	3926.72	8.81062	13.65	0.580543	0.01	0	0.601987	0.01	0	0.601987	4508.98	0.225122	0.774878	0	1.90918
27/12/2007	3848.4	9.14467	14.56	0.545926	0.01	0	0.565924	0.01	0	0.565924	4450.46	0.228475	0.771525	0	1.88617
27/03/2008	3772.1	9.45886	15.47	0.51362	0.01	0	0.532286	0.01	0	0.532286	4390.72	0.231309	0.768691	0	1.86402
26/06/2008	3697.75	9.75451	16.38	0.483446	0.01	0	0.500881	0.01	0	0.500881	4329.98	0.233691	0.766309	0	1.84269
25/09/2008	3625.26	10.0329	17.29	0.455245	0.01	0	0.471542	0.01	0	0.471542	4268.44	0.235678	0.764322	0	1.82214
25/12/2008	3554.58	10.295	18.2	0.428873	0.01	0	0.444114	0.01	0	0.444114	4206.3	0.237321	0.762679	0	1.80233
26/03/2009	3485.65	10.542	19.11	0.404198	0.01	0	0.418459	0.01	0	0.418459	4143.73	0.238664	0.761336	0	1.78323
25/06/2009	3418.41	10.7748	20.02	0.381101	0.01	0	0.394451	0.01	0	0.394451	4080.87	0.239744	0.760256	0	1.7648
24/09/2009	3352.82	10.9944	20.93	0.359473	0.01	0	0.371975	0.01	0	0.371975	4017.88	0.240596	0.759404	0	1.74703
24/12/2009	3288.83	11.2015	21.84	0.339212	0.01	0	0.350924	0.01	0	0.350924	3954.88	0.24125	0.75875	0	1.72988
25/03/2010	3226.38	11.397	22.75	0.320227	0.01	0	0.331202	0.01	0	0.331202	3891.99	0.241733	0.758267	0	1.71332
24/06/2010	3165.44	11.5816	23.66	0.302431	0.01	0	0.312719	0.01	0	0.312719	3829.3	0.242069	0.757931	0	1.69733
23/09/2010	3105.97	11.756	24.57	0.285747	0.01	0	0.295392	0.01	0	0.295392	3766.92	0.242279	0.757721	0	1.68189
23/12/2010	3047.92	11.9208	25.48	0.270101	0.01	0	0.279146	0.01	0	0.279146	3704.92	0.242381	0.757619	0	1.66697
24/03/2011	2991.25	12.0765	26.39	0.255426	0.01	0	0.26391	0.01	0	0.26391	3643.38	0.242394	0.757606	0	1.65256
23/06/2011	2935.93	12.2239	27.3	0.241658	0.01	0	0.249618	0.01	0	0.249618	3582.37	0.242331	0.757668	0	1.63863
22/09/2011	2881.91	12.3633	28.21	0.228741	0.01	0	0.236209	0.01	0	0.236209	3521.93	0.242208	0.757792	0	1.62516

14. Once the prediction is finished, export the following from the model to EXCEL:

- GOR
- Oil Saturation (equivalent of liquid drop out)

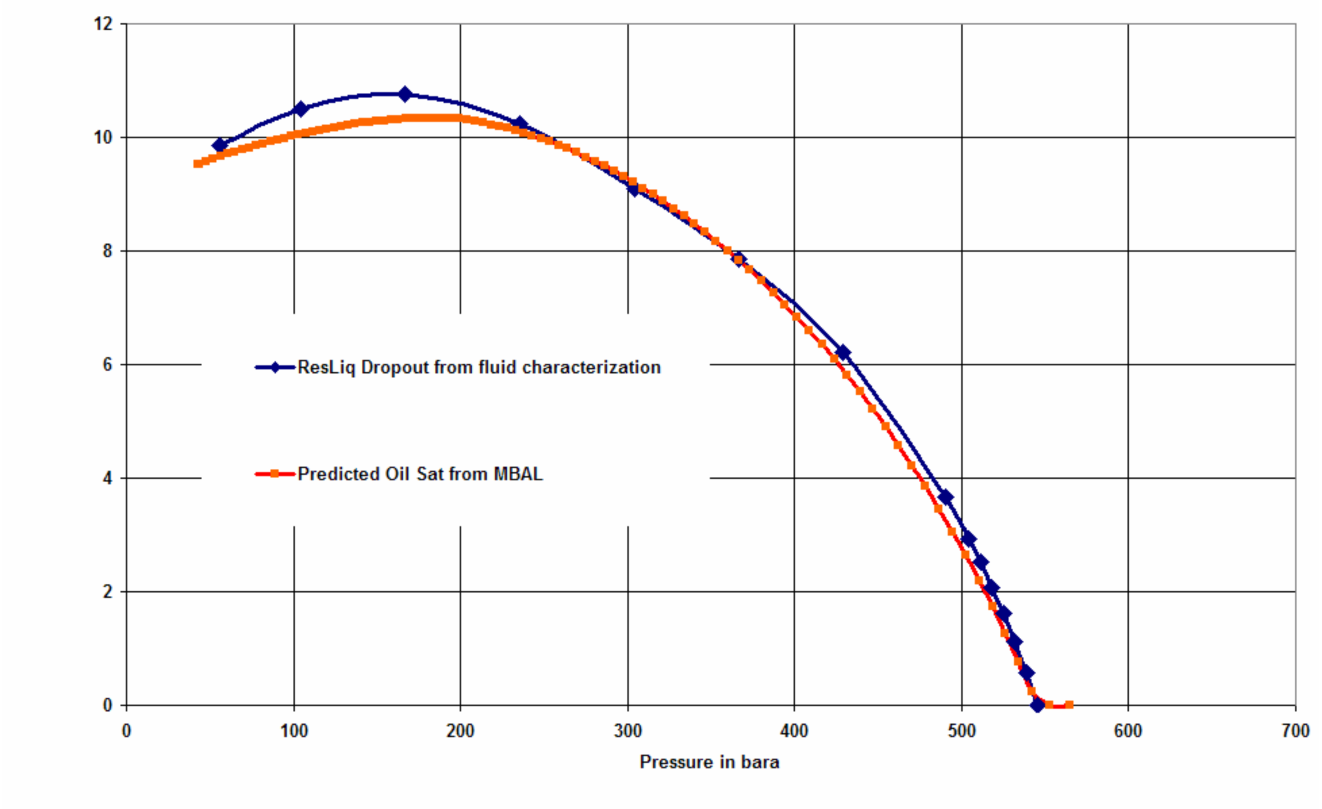
- Gas Recovery

15. Once imported onto the EXCEL spread sheet, the following variables can be plotted versus pressure allowing for a comparison between the **MBAL** and PVTP results:

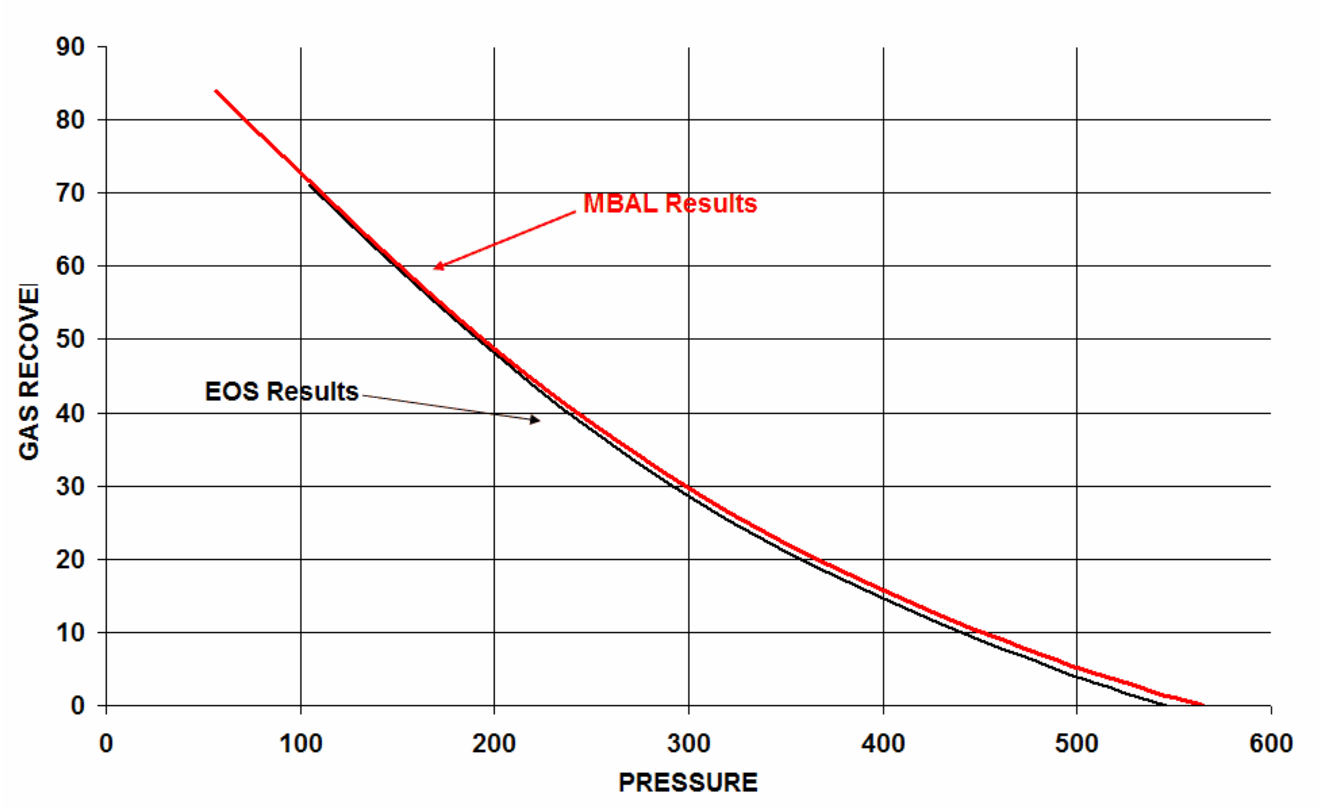
- Produced GOR
- Liquid dropout
- Gas recovery

Note that the liquid drop out in **MBAL** is represented by the oil saturation in the tank, which is a fraction and needs to be converted to a % value.

The results of this validation for one case are shown below:



Liquid Drop out Comparison.



Gas Recovery Curve

Results of Validation:

On basis of these three graphs, it can be concluded that for this particular case, the Black Oil model is able to replicate the behaviour of a fully compositional model and as such we can use the Black Oil PVT approach within **MBAL** tool to study this reservoir.

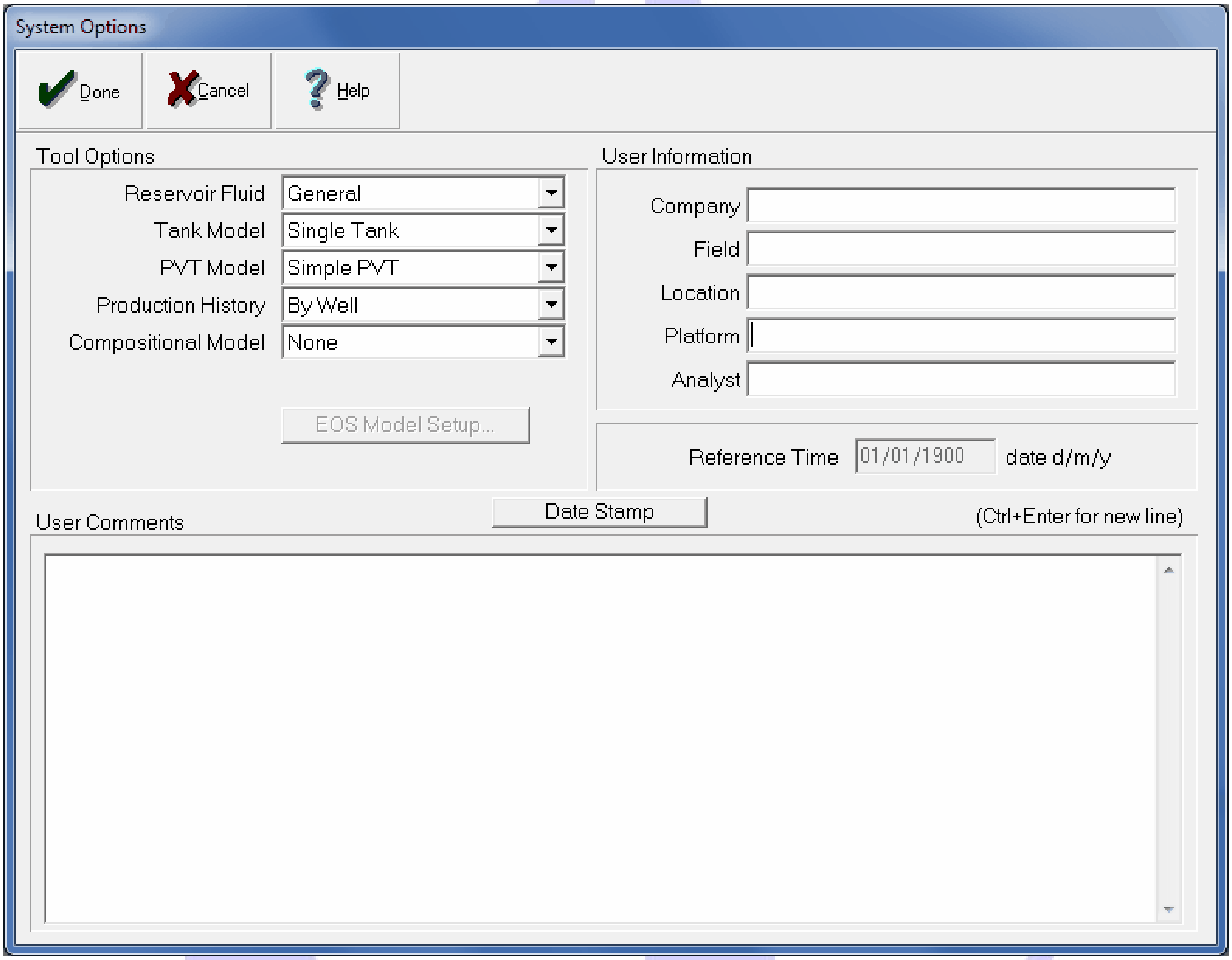
In Case the Black Oil properties of the fluid do not match those predicted with the Compositional method, it indicates that the Black Oil Condensate PVT model (which is a mathematical model [and not a correlation based approach]) may not be suitable for the stated fluid. In this case the fluid should be modelled using the Compositional PVT approach in MBAL.

2.3.4.2.13 PVT for General Model

In **MBAL** if the oil, gas or condensate options are selected, the material balance equations are solved specifically for the type of fluid selected. So, in an oil reservoir with a gas cap, the gas cap will be defined in the PVT section as the “m” value. The properties of the gas cap will be defined by the gas gravity entered in the PVT screen.

However, when the situation to be modelled is that of a condensate with an oil leg, then the above PVT definitions are not adequate. The 'General' description was added to the program in order to accommodate this situation and be able to solve the material balance equations for any type of fluid.

If the 'General' fluid model has been selected in **Options** menu:

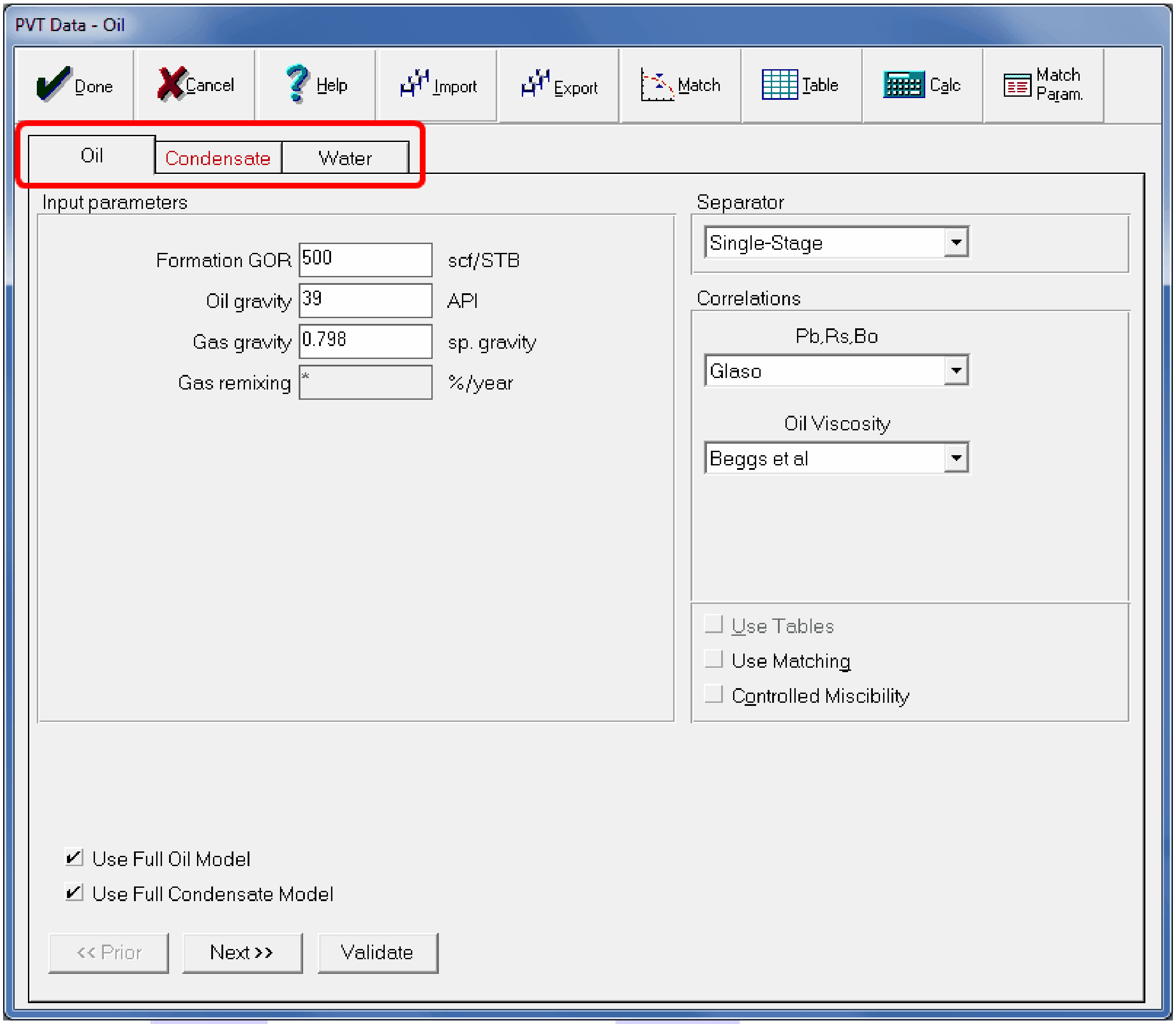

System Options
Done
Cancel
Help
Tool Options
User Information
EOS Model Setup...
Date Stamp
(Ctrl+Enter for new line)
User Comments

Reservoir Fluid: General
Tank Model: Single Tank
PVT Model: Simple PVT
Production History: By Well
Compositional Model: None

Company:
Field:
Location:
Platform:
Analyst:

Reference Time: 01/01/1900 date d/m/y

The following screen will appear in the PVT definition for the fluid:


PVT Data - Oil
Done
Cancel
Help
Import
Export
Match
Table
Calc
Match Param.
Oil
Condensate
Water
<< Prior
Next >>
Validate

Input parameters

Formation GOR 500 scf/STB

Oil gravity 39 API

Gas gravity 0.798 sp. gravity

Gas remixing * %/year

Separator: Single-Stage

Correlations

Pb,Rs,Bo: Glaso

Oil Viscosity: Beggs et al

☐ Use Tables

☐ Use Matching

☐ Controlled Miscibility

☑ Use Full Oil Model

☑ Use Full Condensate Model

There are three tabs on the above screen:

Oil	This tab will display the same fields as on the standard oil or variable PVT dialogue. The only difference is that the water inputs and the gas impurities are not displayed
Gas	This tab will display the same fields as on the standard retrograde condensate dialogue. The only difference is that the water inputs are not displayed
Water	This tab displays the water inputs that normally appear on the oil or retrograde condensate

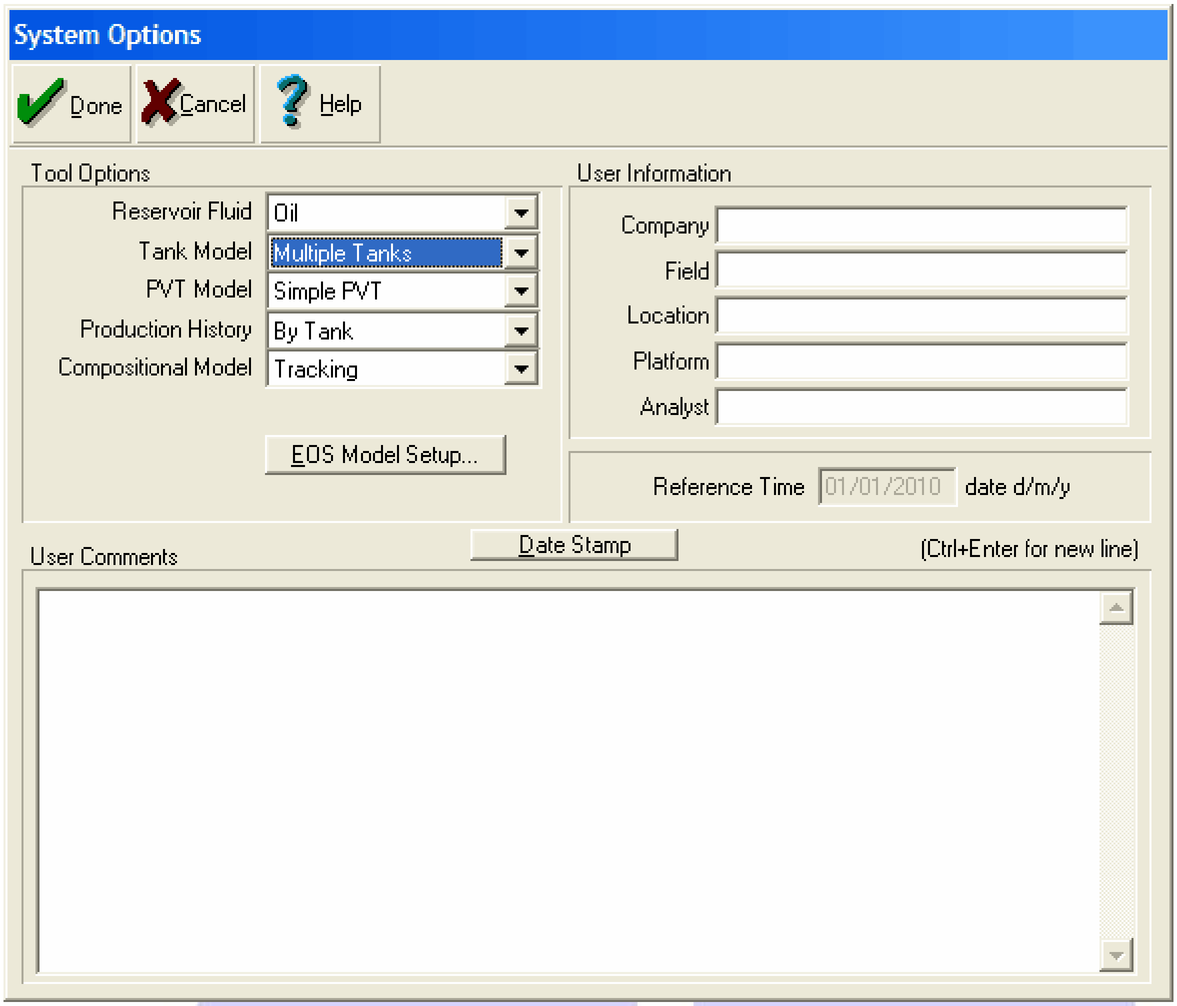
In this case, the oil properties are calculated from the model entered in the oil tab, the gas properties are calculated from the model entered in the gas tab and the water properties are calculated from the model entered in the water tab.

The **Import**, **Match**, **Table** and **Match** Parameters buttons on each tab will operate on each phase model separately. For example, each phase can be matched separately. However the results calculated from the Calc button will always be from the combination of the three models.

It is also possible to exclude the use of the full model for either the oil or gas phase. This allows compatibility with old oil or retrograde condensate models. For example, if a full model for the gas phase is unavailable, the '**Use Full Gas Model'** option could be switched off. In this case, the gas properties will be calculated from the oil model i.e. the same as the standard oil model. Note that the water properties will still be calculated from the data in the water tab.

2.3.4.2.14 Multiple PVT Definitions

In ***MBAL***, it is possible to have more than one tank described with transmissibility between them that would simulate different regions of a reservoir. If the fluid in the different compartments are different, different PVT models can be defined for each tank in MBAL. The tank model should be defined as "Multiple Tanks".


System Options
Done
Cancel
Help
EOS Model Setup...
Date Stamp

Tool Options

Reservoir Fluid: Oil
Tank Model: Multiple Tanks
PVT Model: Simple PVT
Production History: By Tank
Compositional Model: Tracking

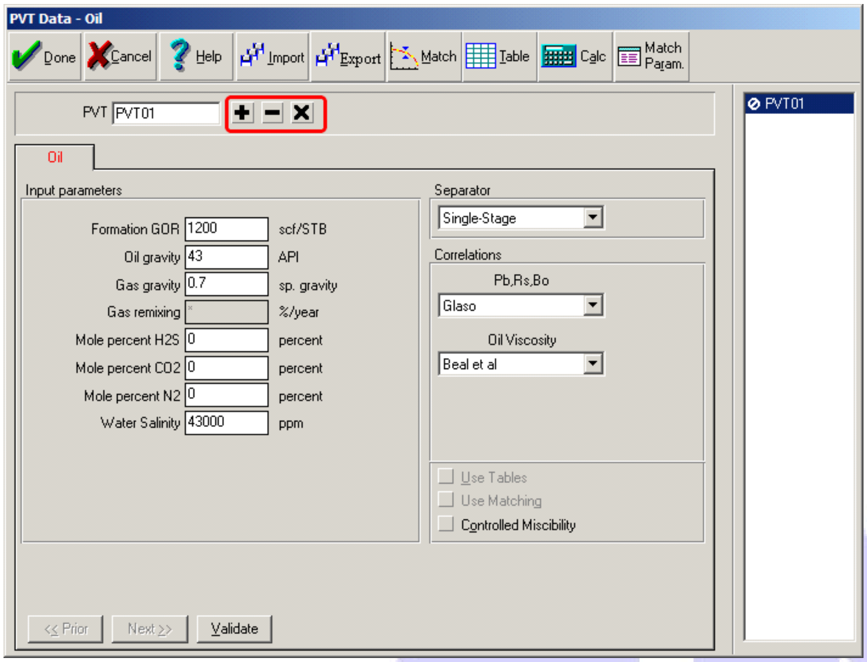
User Information

Company
Field
Location
Platform
Analyst

Reference Time 01/01/2010 date d/m/y

User Comments (Ctrl+Enter for new line)

In the PVT section, the following screen will be viewed:


PVT Data - Oil
Done
Cancel
Help
Import
Export
Match
Table
Calc
Match Param.
Oil
<< Prior
Next >>
Validate

PVT PVT01

PVT01

Input parameters

Formation GOR 1200 scf/STB
Oil gravity 43 API
Gas gravity 0.7 sp. gravity
Gas remixing %/year
Mole percent H2S 0 percent
Mole percent CO2 0 percent
Mole percent N2 0 percent
Water Salinity 43000 ppm

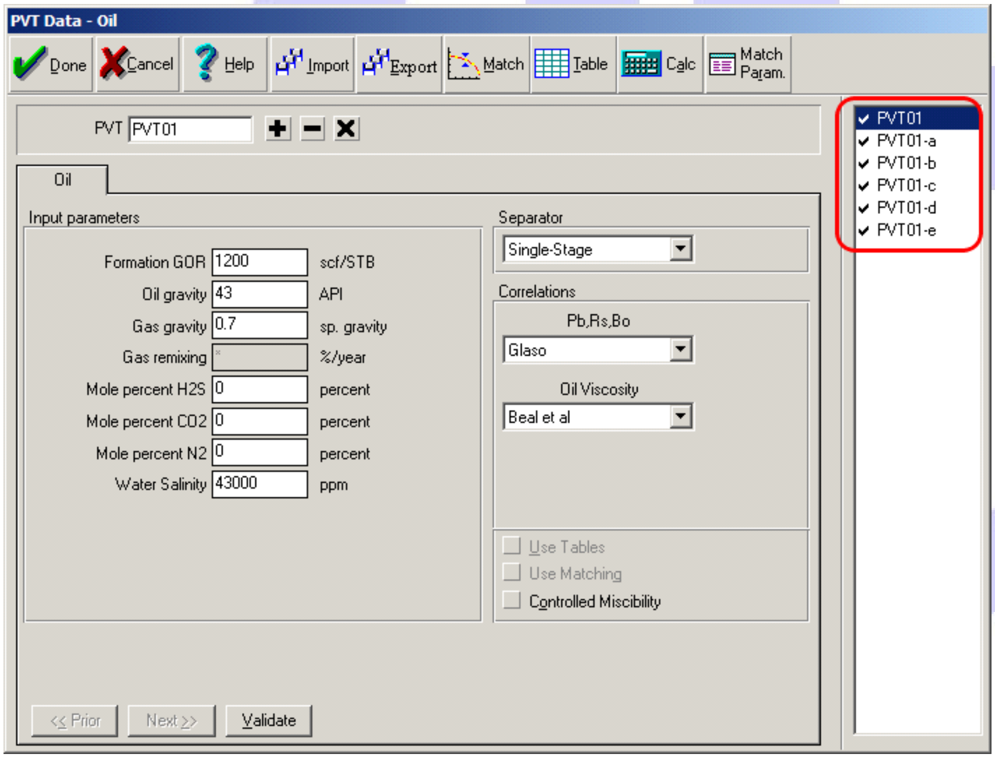
Separator: Single-Stage

Correlations
Pb,Rs,Bo: Glaso
Oil Viscosity: Beal et al

☐ Use Tables
☐ Use Matching
☐ Controlled Miscibility

The buttons shown above will allow the user to add (+) and delete (-) streams with different PVT definitions. The (x) button copies streams.

So, it the (x) button is clicked 5 times, 5 streams will be created accordingly (with the same properties as the original):


PVT Data - Oil
Done
Cancel
Help
Import
Export
Match
Table
Calc
Match Param.
Oil
<< Prior
Next >>
Validate

PVT PVT01

✓ PVT01
✓ PVT01-a
✓ PVT01-b
✓ PVT01-c
✓ PVT01-d
✓ PVT01-e

Input parameters

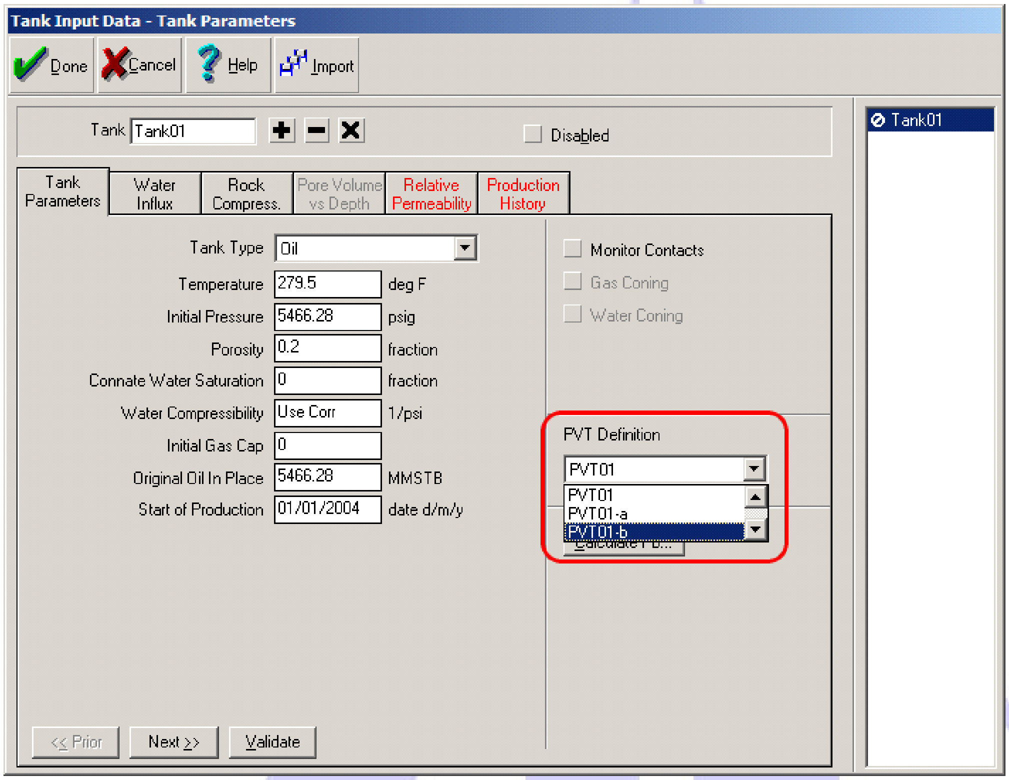
Formation GOR 1200 scf/STB
Oil gravity 43 API
Gas gravity 0.7 sp. gravity
Gas remixing %/year
Mole percent H2S 0 percent
Mole percent CO2 0 percent
Mole percent N2 0 percent
Water Salinity 43000 ppm

Separator: Single-Stage

Correlations
Pb,Rs,Bo: Glaso
Oil Viscosity: Beal et al

☐ Use Tables
☐ Use Matching
☐ Controlled Miscibility

The title for each stream can then be selected from the 'PVT definitions' in the reservoir screen:


Tank Input Data - Tank Parameters
Done
Cancel
Help
Import
Disabled
Tank01
Tank Parameters
Water Influx
Rock Compress.
Pore Volume vs Depth
Relative Permeability
Production History
Monitor Contacts
Gas Coning
Water Coning
PVT Definition
PVT01
PVT01-a
PVT01-b
Calculate PB...
<< Prior
Next >>
Validate

Tank Tank01

Tank Type Oil

Temperature 279.5 deg F

Initial Pressure 5466.28 psig

Porosity 0.2 fraction

Connate Water Saturation 0 fraction

Water Compressibility Use Corr 1/psi

Initial Gas Cap 0

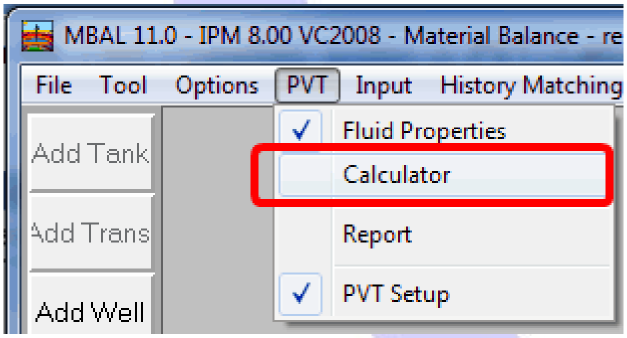
Original Oil In Place 5466.28 MMSTB

Start of Production 01/01/2004 date d/m/y

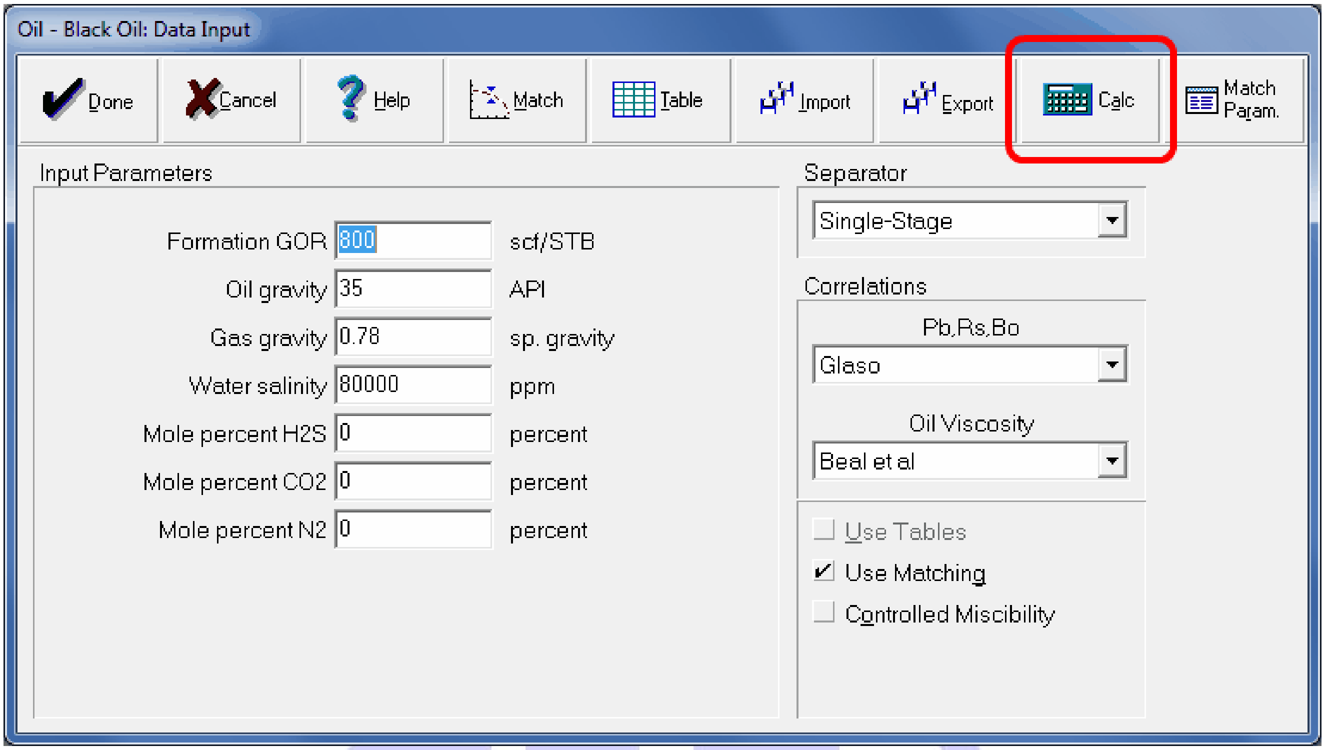
PVT Definition PVT01

2.3.4.2.15 Checking the PVT calculations

The quality of the PVT data can be verified by selecting either; **Calc** in the 'Fluid Properties' screen or **PVT | Calculator**. The PVT calculator may be used to generated PVT properties to be used in any other third party application, e. g. numerical simulator for instance.


MBAL 11.0 - IPM 8.00 VC2008 - Material Balance - re
File
Tool
Options
PVT
Input
History Matching
Add Tank
Add Trans
Add Well
✓ Fluid Properties
Calculator
Report
✓ PVT Setup

OR

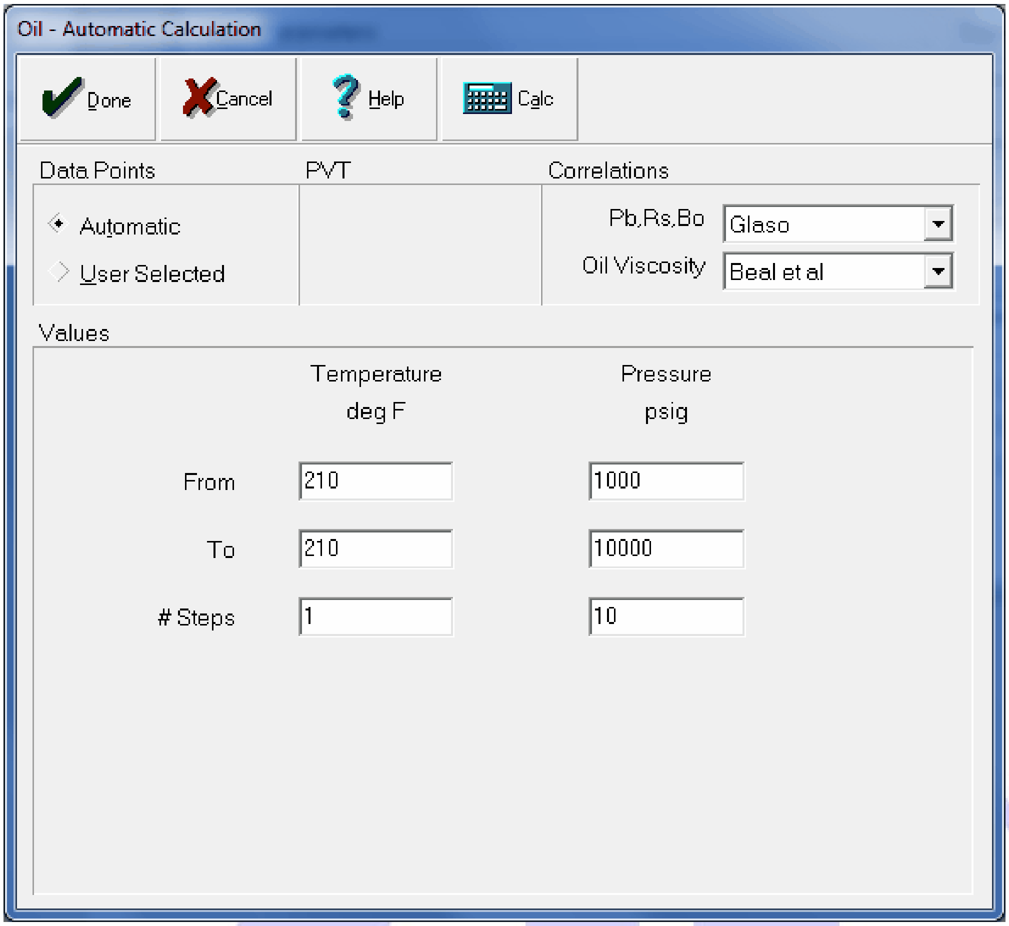

Oil - Black Oil: Data Input
Done
Cancel
Help
Match
Table
Import
Export
Calc
Match Param.
Input Parameters
Separator
Correlations
Pb,Rs,Bo
Oil Viscosity

Formation GOR 800 scf/STB
Oil gravity 35 API
Gas gravity 0.78 sp. gravity
Water salinity 80000 ppm
Mole percent H2S 0 percent
Mole percent CO2 0 percent
Mole percent N2 0 percent

Separator: Single-Stage
Pb,Rs,Bo: Glaso
Oil Viscosity: Beal et al

☐ Use Tables
☑ Use Matching
☐ Controlled Miscibility

Both of the methods will result in the same dialogue box being prompted:



○ Automatic
○ User Selected

Pb,Rs,Bo: Glaso
Oil Viscosity: Beal et al

Values

	Temperature deg F	Pressure psig
From	210	1000
To	210	10000
# Steps	1	10

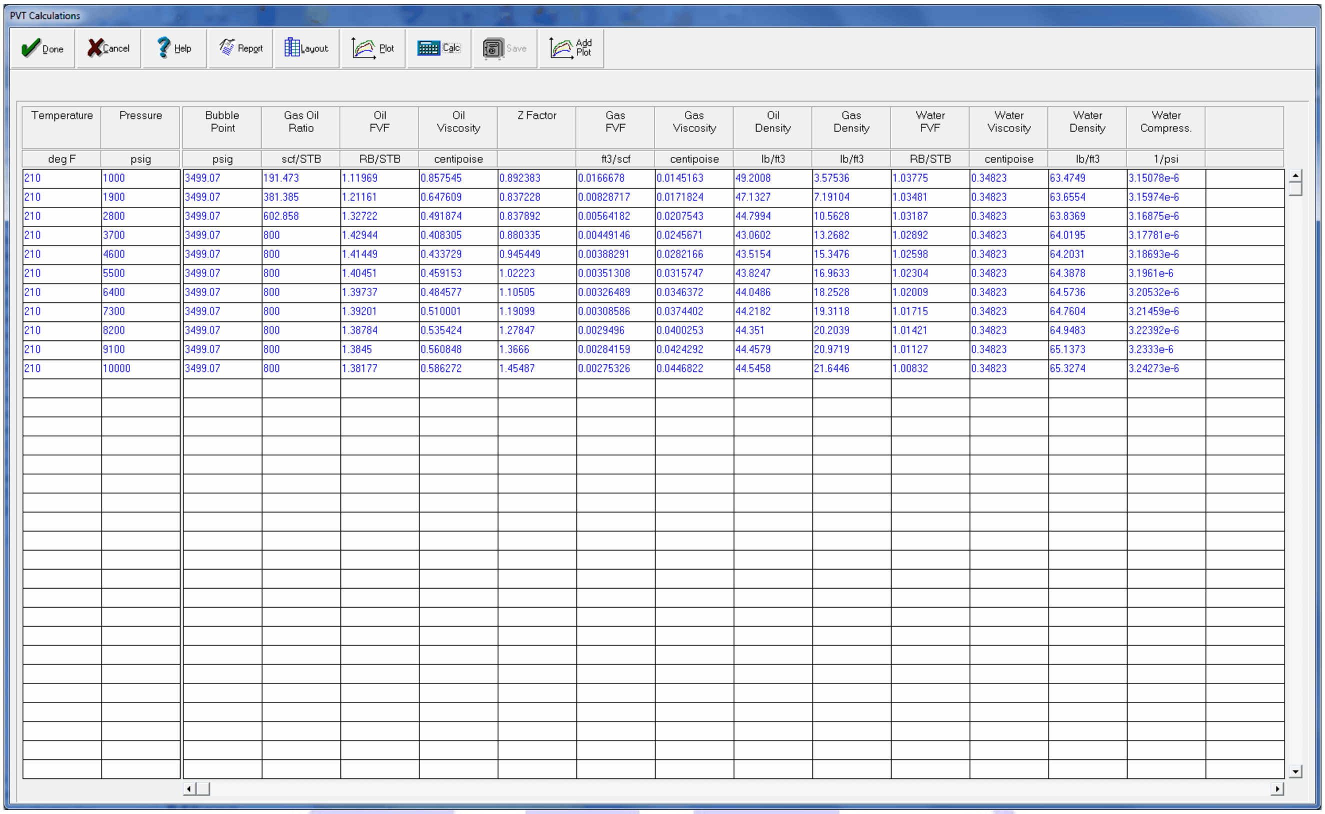
Input Data

Data points	**Automatic**	Enter a range of pressures and temperatures, and the number of steps to calculate for each
	User selected	A separate input screen appears that allows for up to 10 specific pressure and temperature points to be entered
Layer	**(for multi-PVT only)** For multi-PVT, this option allows the user to specify which layer the calculations are to be performed upon	
Correlations	Select the correlations of interest, or those known to best 'fit' the region or fluid type. The correlations displayed default from the 'Data Input' screen. The methods selected can be changed to test the other correlations	
Values	Values input varies depending on the data points selection:	
	Automatic	Enter: • A range of pressures and temperatures • The number of steps to calculate for each variable (i.e. pressure and temperature)..

<table>
<tr>
<td></td>
<td>
<table>
<tr><td></td><td>MBAL will calculate the values of pressure and temperature required and set up points to combine all the different values of pressure and temperature. For example, if there are 3 pressure values and 5 temperature values, there will be 15 points in total</td></tr>
<tr><td>User-defined</td><td>enter the pressure and temperature required for each data point directly</td></tr>
</table>
If the controlled miscibility option has been selected then the bubble point is not fixed. So the bubble point (Pb) at which the calculations are to be carried out will also need to be entered
</td>
</tr>
<tr>
<td>Calc</td>
<td>Displays a dialogue box which allows the user to start the calculation and displays the results of the calculation. See PVT Calculation Results for more information</td>
</tr>
</table>

These are the steps to perform a PVT calculation:

- Select the correlations to apply. The default correlations from the 'Fluid Properties' input screen will initially be available however, these can be altered if other correlations are to be tested.
- Check the **Data Points** method of calculation *(*Automatic or User Selected*)*
- If the controlled miscibility option has been selected then the bubble point will not be fixed. This means that the bubble point Pb at which the calculations are to be carried out needs to be entered.
- Click **Calc**. A calculation screen showing the results of the previous calculation appears.

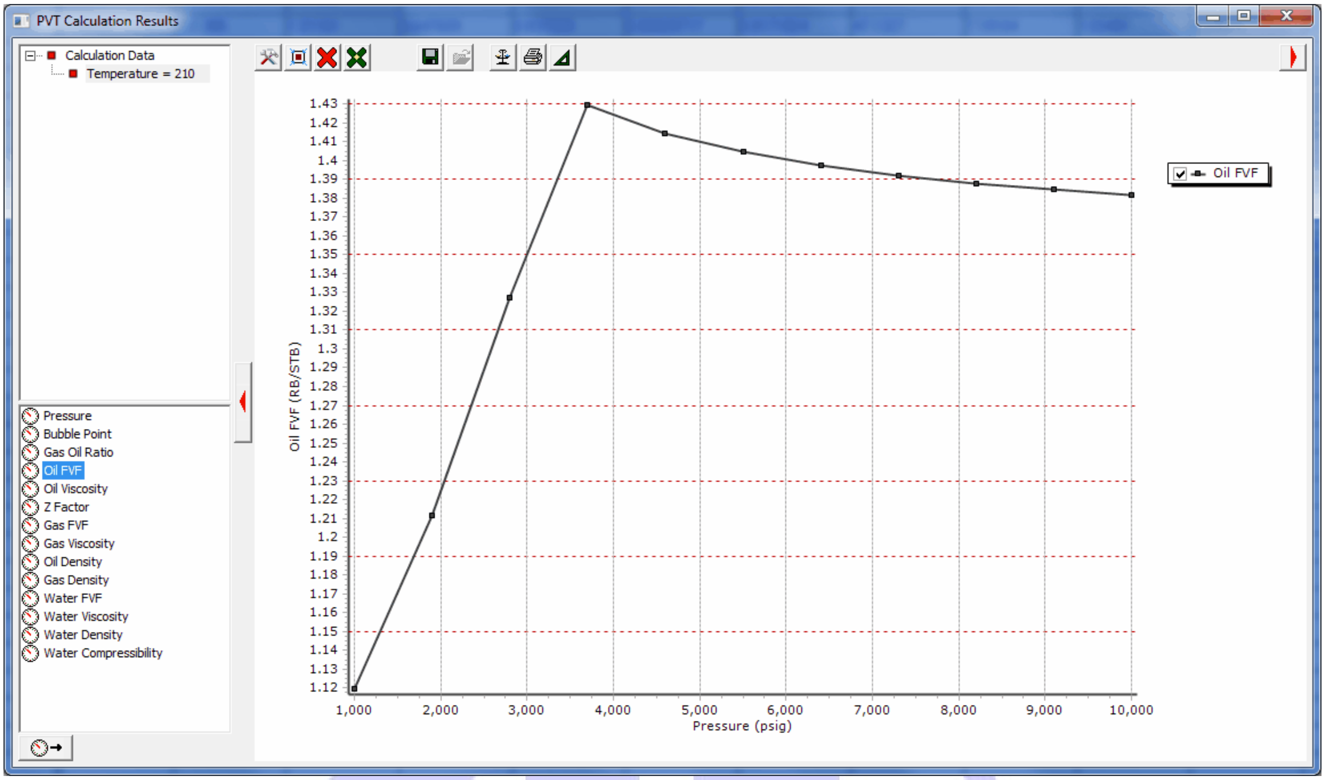


Temperature	Pressure	Bubble Point	Gas Oil Ratio	Oil FVF	Oil Viscosity	Z Factor	Gas FVF	Gas Viscosity	Oil Density	Gas Density	Water FVF	Water Viscosity	Water Density	Water Compress.
deg F	psig	psig	scf/STB	RB/STB	centipoise		ft3/scf	centipoise	lb/ft3	lb/ft3	RB/STB	centipoise	lb/ft3	1/psi
210	1000	3499.07	191.473	1.11969	0.857545	0.892383	0.0166678	0.0145163	49.2008	3.57536	1.03775	0.34823	63.4749	3.15078e-6
210	1900	3499.07	381.385	1.21161	0.647609	0.837228	0.00828717	0.0171824	47.1327	7.19104	1.03481	0.34823	63.6554	3.15974e-6
210	2800	3499.07	602.858	1.32722	0.491874	0.837892	0.00564182	0.0207543	44.7994	10.5628	1.03187	0.34823	63.8369	3.16875e-6
210	3700	3499.07	800	1.42944	0.408305	0.880335	0.00449146	0.0245671	43.0602	13.2682	1.02892	0.34823	64.0195	3.17781e-6
210	4600	3499.07	800	1.41449	0.433729	0.945449	0.00388291	0.0282166	43.5154	15.3476	1.02598	0.34823	64.2031	3.18693e-6
210	5500	3499.07	800	1.40451	0.459153	1.02223	0.00351308	0.0315747	43.8247	16.9633	1.02304	0.34823	64.3878	3.1961e-6
210	6400	3499.07	800	1.39737	0.484577	1.10505	0.00326489	0.0346372	44.0486	18.2528	1.02009	0.34823	64.5736	3.20532e-6
210	7300	3499.07	800	1.39201	0.510001	1.19099	0.00308586	0.0374402	44.2182	19.3118	1.01715	0.34823	64.7604	3.21459e-6
210	8200	3499.07	800	1.38784	0.535424	1.27847	0.0029496	0.0400253	44.351	20.2039	1.01421	0.34823	64.9483	3.22392e-6
210	9100	3499.07	800	1.3845	0.560848	1.3666	0.00284159	0.0424292	44.4579	20.9719	1.01127	0.34823	65.1373	3.2333e-6
210	10000	3499.07	800	1.38177	0.586272	1.45487	0.00275326	0.0446822	44.5458	21.6446	1.00832	0.34823	65.3274	3.24273e-6

Command buttons

Report	Allows reporting of a listing of the calculation results. The user will be prompted to select the output format. Click 'Report' again to generate the listing. See reports to get a description of the available output formats
Layout	This option allows control over which columns are displayed in the table. For example, it may only be desired to examine oil viscosity and water density which would normally require scrolling horizontally across the table
Plot	This option displays a graph which can display the calculated variables plotted against either pressure or temperature. Only one calculated variable can be plotted at once. The variable plotted can be changed using the 'Variables' menu option
Calc	Allows re-calculation of the PVT variables. Use this option if values of pressure and temperature required in the previous dialogue were re-entered

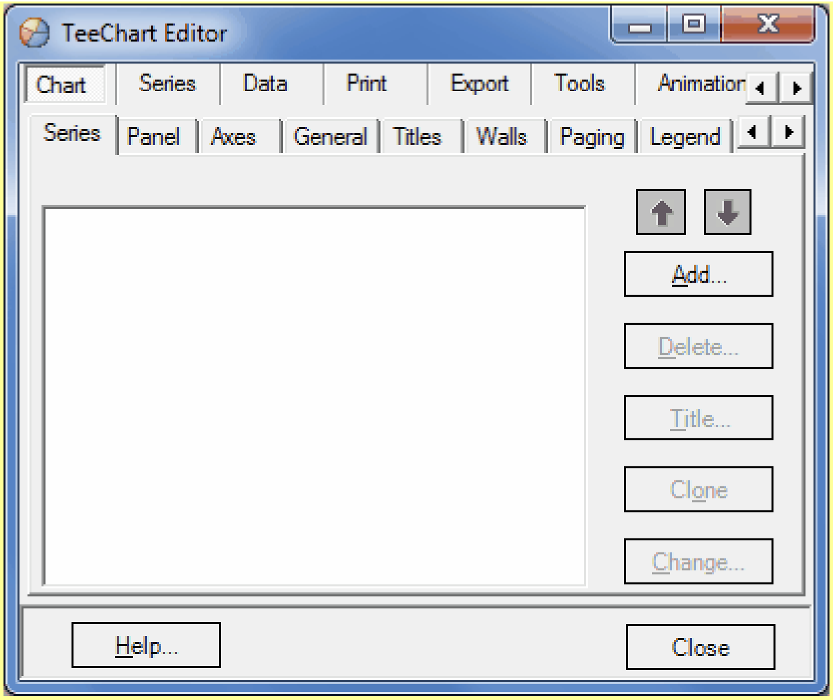
- Click **Calc** again to start the calculation.
- To view the calculation results graphically, click **Plot**. A graphics screen similar to the following appears. Multiple plots can be created by selecting **Add Plot**

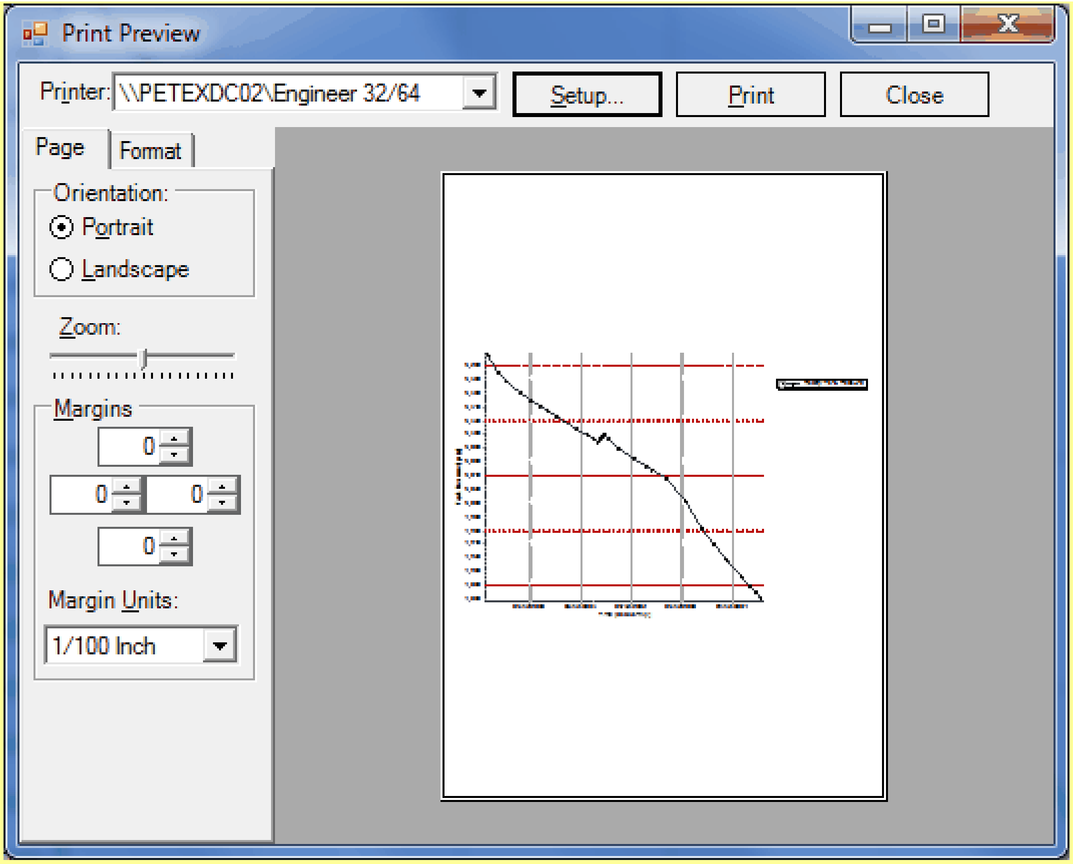

PVT Calculation Results
Calculation Data
Temperature = 210
Pressure
Bubble Point
Gas Oil Ratio
Oil FVF
Oil Viscosity
Z Factor
Gas FVF
Gas Viscosity
Oil Density
Gas Density
Water FVF
Water Viscosity
Water Density
Water Compressibility
Oil FVF (RB/STB)
1.43
1.42
1.41
1.4
1.39
1.38
1.37
1.36
1.35
1.34
1.33
1.32
1.31
1.3
1.29
1.28
1.27
1.26
1.25
1.24
1.23
1.22
1.21
1.2
1.19
1.18
1.17
1.16
1.15
1.14
1.13
1.12
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
Pressure (psig)
☑ Oil FVF

The temperature values used for the calculation can be selected in the upper left hand section while the PVT variables can be selected from the bottom left hand section. The program allows modification of the plot display to be carried out; i.e. alteration of plot colours, labels and scales or the variables displayed on the X and Y axes.

To change a plot display, use any of the following menu options on the plot menu bar.

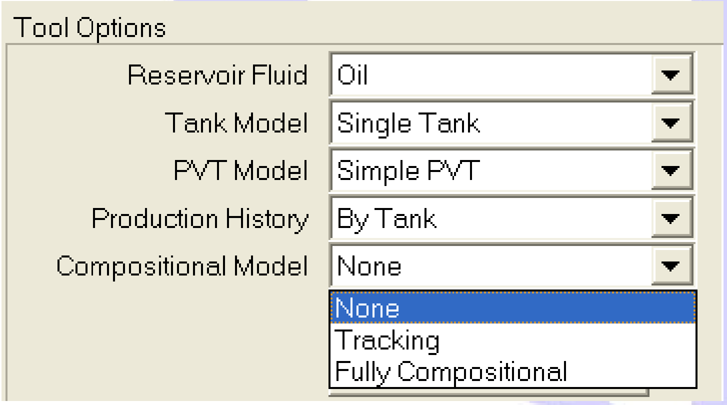
🛠	Tee-chart editor for new Tee chart plotting feature in MBAL. The editor can be used to edit the plot display including axis, legend, data set, scales, colours e.t.c.

	 TeeChart Editor Chart Series Data Print Export Tools Animation Series Panel Axes General Titles Walls Paging Legend Add... Delete... Title... Clone Change... Help... Close
▣	Cancels any zoom and redraws the original plot
❌	Removes a single series from the plot through a selection interface
✖	Removes multiple series from the plot through a selection screen
💾	Use this option to save a plotting configuration which can be recalled for use later.
📂	Use this option to retrieve a saved plotting configuration
⚓	Quick access option to edit scales, legend and labels
🖨	Use to print a hardcopy of the plot(s). Selecting this option brings up the interface below where the various printers configured to the computer can be selected from. Other options include being able to select an orientation or setup paper size e.t.c.

	 Print Preview Setup... Print Close Page Format Zoom: MarginsPrinter: \\PETEXDC02\Engineer 32/64 Orientation: ● Portrait ○ Landscape Margins: 0 0 0 0 Margin Units: 1/100 Inch
◢	Quick access option to edit line widths and symbol sizes

2.3.4.3 Compositional Modelling

These can be selected from the 'Options' screen as shown below:


Tool Options

Reservoir Fluid: Oil

Tank Model: Single Tank

PVT Model: Simple PVT

Production History: By Tank

Compositional Model: None

None
Tracking
Fully Compositional

In **MBAL** there are two ways of utilising fluid compositions: 'Composition Tracking' and 'Fully compositional'.

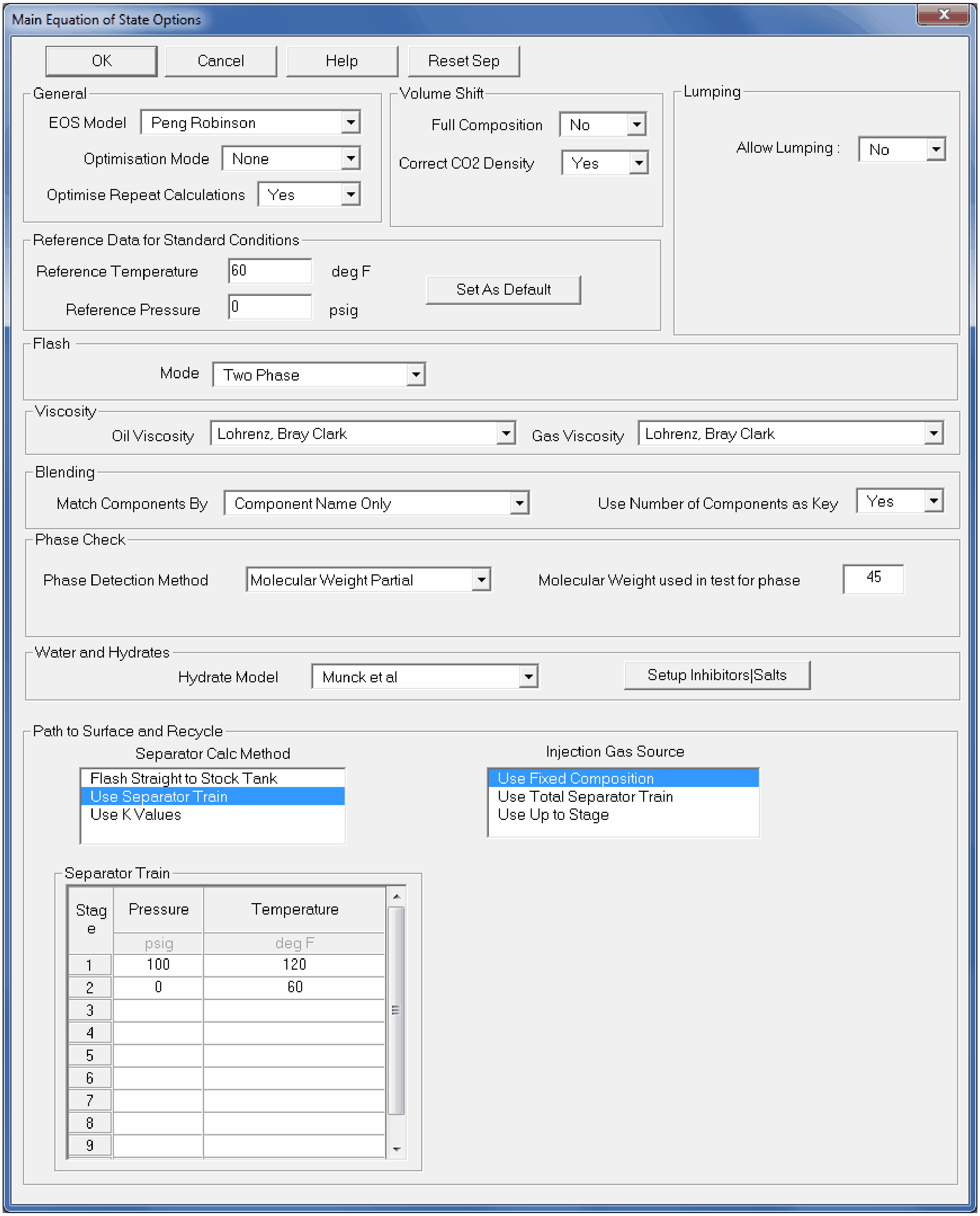
Tracking	uses a black oil model for the PVT properties (Bo, GOR etc) and simply track the compositions by flashing the fluid at the different resulting pressures during the calculations
Fully Compositional	uses the composition to calculate all the fluid properties required during the calculations. The produced composition is also reported at each time-step

The following sections will describe the data entry in the relevant screens in order to set up the models for both compositional tracking and the full EOS calculation.

2.3.4.3.1 EOS Model Setup

The 'EOS Model Setup' section is enabled as soon as the user selects either the 'tracking' or 'fully compositional' methods from the options menu.

The 'EOS Model Setup' button needs to be activated. Accessing this screen will show the different options for the EOS:



General

EOS Model: Peng Robinson

Optimisation Mode: None

Optimise Repeat Calculations: Yes

Volume Shift

Full Composition: No

Correct CO2 Density: Yes

Lumping

Allow Lumping : No

Reference Data for Standard Conditions

Reference Temperature: 60 deg F

Reference Pressure: 0 psig

Flash

Mode: Two Phase

Viscosity

Oil Viscosity: Lohrenz, Bray Clark

Gas Viscosity: Lohrenz, Bray Clark

Blending

Match Components By: Component Name Only

Use Number of Components as Key: Yes

Phase Check

Phase Detection Method: Molecular Weight Partial

Molecular Weight used in test for phase: 45

Water and Hydrates

Hydrate Model: Munck et al

Path to Surface and Recycle

Separator Calc Method

- Flash Straight to Stock Tank
- Use Separator Train
- Use K Values

Injection Gas Source

- Use Fixed Composition
- Use Total Separator Train
- Use Up to Stage

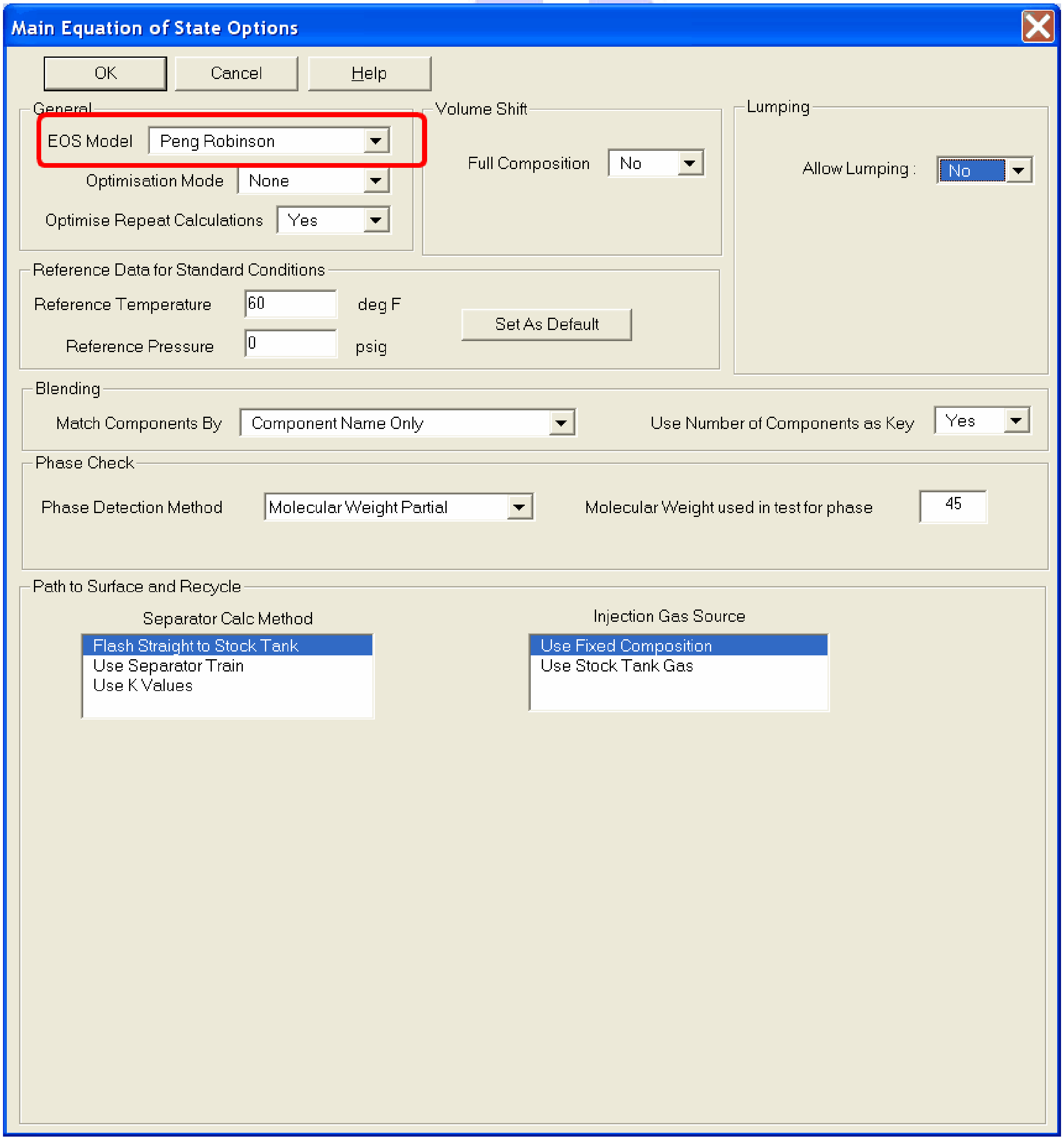
Separator Train

Stage	Pressure psig	Temperature deg F
1	100	120
2	0	60
3		
4		
5		
6		
7		
8		
9		

These options should reflect the EOS available for the fluid (from *PVTP* for example) and the process (path) the fluid follows to standard conditions (which will affect the volumes and quality of the resulting fluid)

2.3.4.3.1.1 EOS Model

This can be set up to Peng Robinson or SRK:



Main Equation of State Options

General
EOS Model: Peng Robinson
Optimisation Mode: None
Optimise Repeat Calculations: Yes

Volume Shift
Full Composition: No

Lumping
Allow Lumping : No

Reference Data for Standard Conditions
Reference Temperature: 60 deg F
Reference Pressure: 0 psig

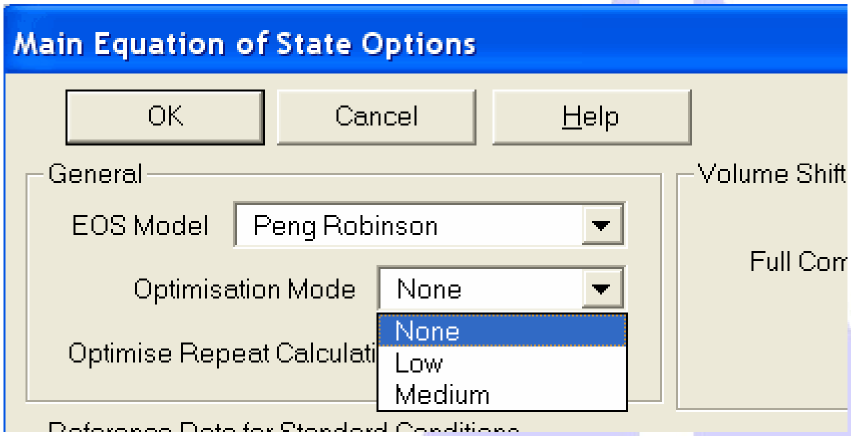
Blending
Match Components By: Component Name Only
Use Number of Components as Key: Yes

Phase Check
Phase Detection Method: Molecular Weight Partial
Molecular Weight used in test for phase: 45

Path to Surface and Recycle
Separator Calc Method:
- Flash Straight to Stock Tank
- Use Separator Train
- Use K Values

Injection Gas Source:
- Use Fixed Composition
- Use Stock Tank Gas

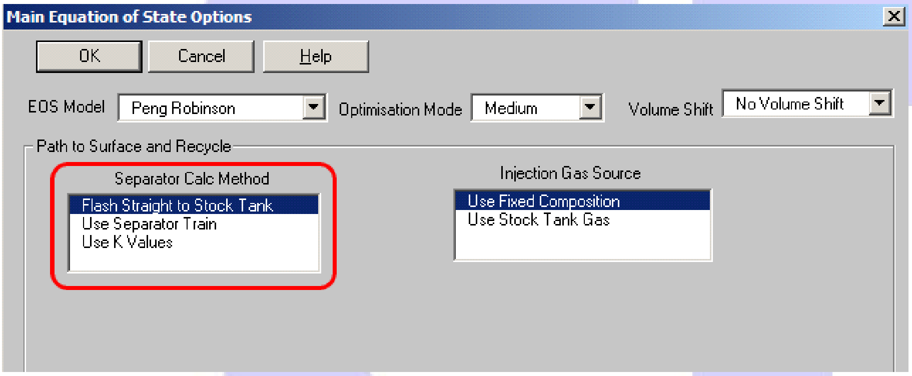
2.3.4.3.1.2 Optimisation Mode


Main Equation of State Options
OK
Cancel
Help
General
EOS Model
Peng Robinson
Optimisation Mode
None
None
Low
Medium
Optimise Repeat Calculati
Volume Shift
Full Com

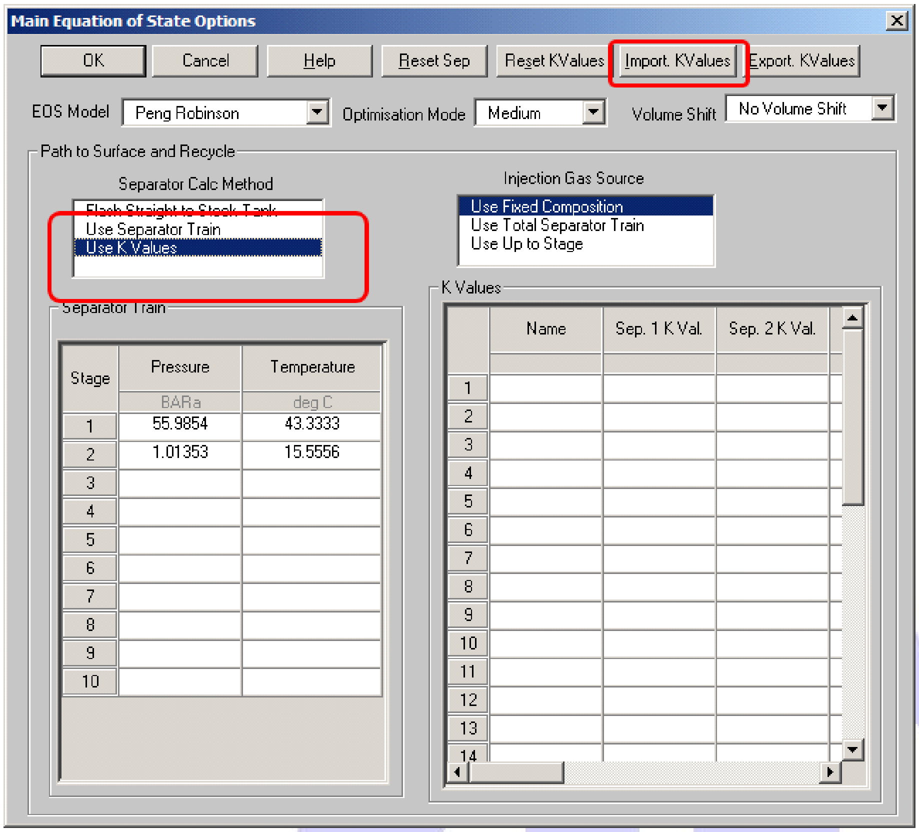
Over the past few years, our PVT experts have been working on ways to speed up the calculation of properties from an EOS model. Speed is one of the main issues with fully compositional models and the options in this section will define the speed of calculations.

The fastest calculations will be done by the default “Medium” option and this should remain as such unless any problems have been detected in the calculations.

2.3.4.3.1.3 Separator Calc Method


Main Equation of State Options
OK
Cancel
Help
EOS Model
Peng Robinson
Optimisation Mode
Medium
Volume Shift
No Volume Shift
Path to Surface and Recycle
Separator Calc Method
Flash Straight to Stock Tank
Use Separator Train
Use K Values
Injection Gas Source
Use Fixed Composition
Use Stock Tank Gas

There are three options in this section of which the first two are self explanatory. Of course, the amount of gas and liquid resulting from the calculations will be different, depending on the path the fluid will take to standard conditions.


Main Equation of State Options
OK
Cancel
Help
Reset Sep
Reset KValues
Import. KValues
Export. KValues
Path to Surface and Recycle
Separator Calc Method
Flash Straight to Stock Tank
Use Separator Train
Use K Values
Injection Gas Source
Use Fixed Composition
Use Total Separator Train
Use Up to Stage
K Values
Name
Sep. 1 K Val.
Sep. 2 K Val.

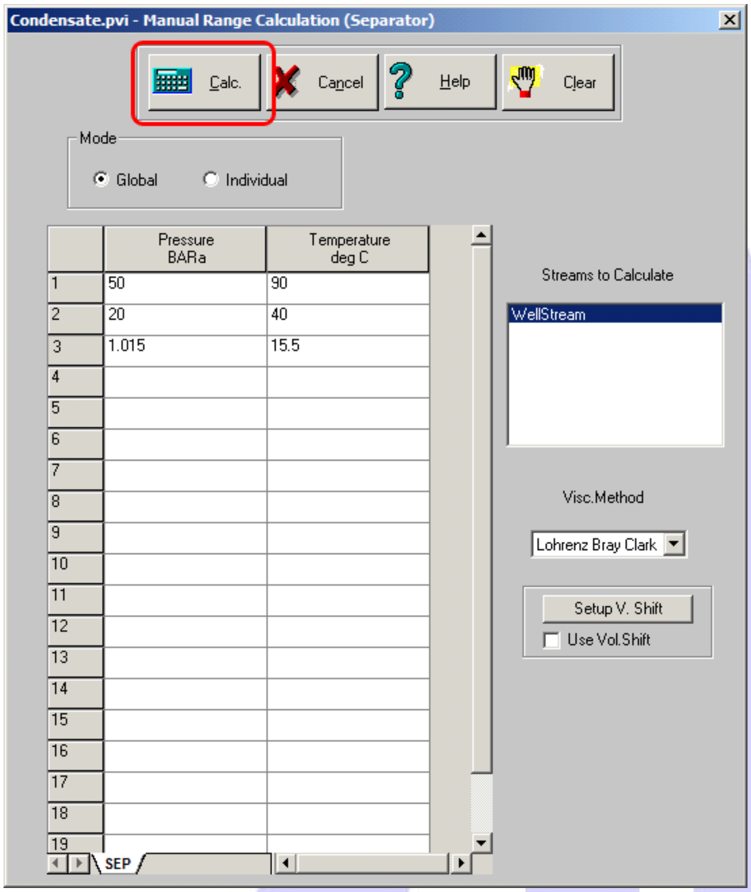
EOS Model: Peng Robinson
Optimisation Mode: Medium
Volume Shift: No Volume Shift
Separator Calc Method: Use K Values
Injection Gas Source: Use Fixed Composition

Separator Train

Stage	Pressure BARa	Temperature deg C
1	55.9854	43.3333
2	1.01353	15.5556
3		
4		
5		
6		
7		
8		
9		
10		

The “Use K Values” option is an addition to the compositional modelling that allows modelling of the process based on K values (equilibrium ratios). This can allow process calculations from systems more complex than separation to be represented as “Pseudo” separators and can be obtained from process simulators.

In **PVTP**, these values can be easily exported by carrying out a separator calculation:



Condensate.pvi - Manual Range Calculation (Separator)

Mode

● Global ○ Individual

	Pressure BARa	Temperature deg C
1	50	90
2	20	40
3	1.015	15.5
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		

Streams to Calculate

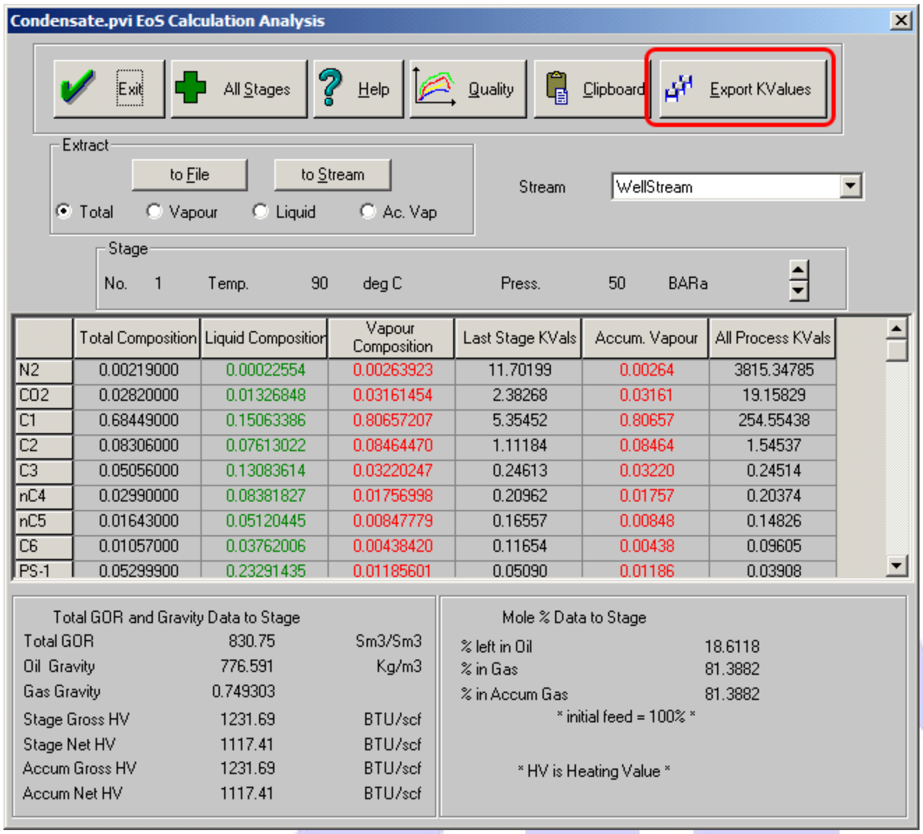
WellStream

Visc.Method

Lohrenz Bray Clark

☐ Use Vol.Shift

Having carried out the calculations, the 'Analysis' tab can be selected to view the components while the 'Export K Values' button can be used to export them:


Condensate.pvi EoS Calculation Analysis
Exit
All Stages
Help
Quality
Clipboard
Export KValues
Extract
to File
to Stream

● Total ○ Vapour ○ Liquid ○ Ac. Vap

Stream WellStream

Stage

No. 1 Temp. 90 deg C Press. 50 BARa

	Total Composition	Liquid Composition	Vapour Composition	Last Stage KVals	Accum. Vapour	All Process KVals
N2	0.00219000	0.00022554	0.00263923	11.70199	0.00264	3815.34785
CO2	0.02820000	0.01326848	0.03161454	2.38268	0.03161	19.15829
C1	0.68449000	0.15063386	0.80657207	5.35452	0.80657	254.55438
C2	0.08306000	0.07613022	0.08464470	1.11184	0.08464	1.54537
C3	0.05056000	0.13083614	0.03220247	0.24613	0.03220	0.24514
nC4	0.02990000	0.08381827	0.01756998	0.20962	0.01757	0.20374
nC5	0.01643000	0.05120445	0.00847779	0.16557	0.00848	0.14826
C6	0.01057000	0.03762006	0.00438420	0.11654	0.00438	0.09605
PS-1	0.05299900	0.23291435	0.01185601	0.05090	0.01186	0.03908

Total GOR and Gravity Data to Stage

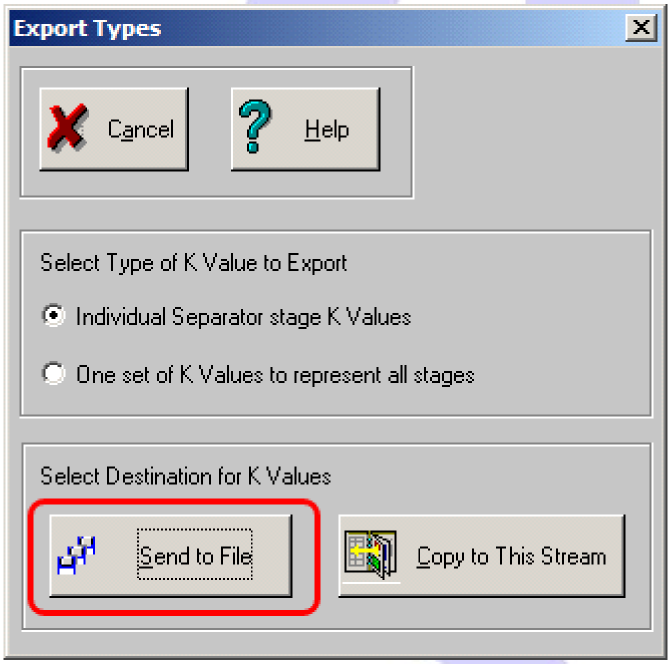
Total GOR	830.75	Sm3/Sm3
Oil Gravity	776.591	Kg/m3
Gas Gravity	0.749303	
Stage Gross HV	1231.69	BTU/scf
Stage Net HV	1117.41	BTU/scf
Accum Gross HV	1231.69	BTU/scf
Accum Net HV	1117.41	BTU/scf

Mole % Data to Stage

% left in Oil	18.6118
% in Gas	81.3882
% in Accum Gas	81.3882

* initial feed = 100% *

* HV is Heating Value *


Export Types
Cancel
Help
Send to File
Copy to This Stream

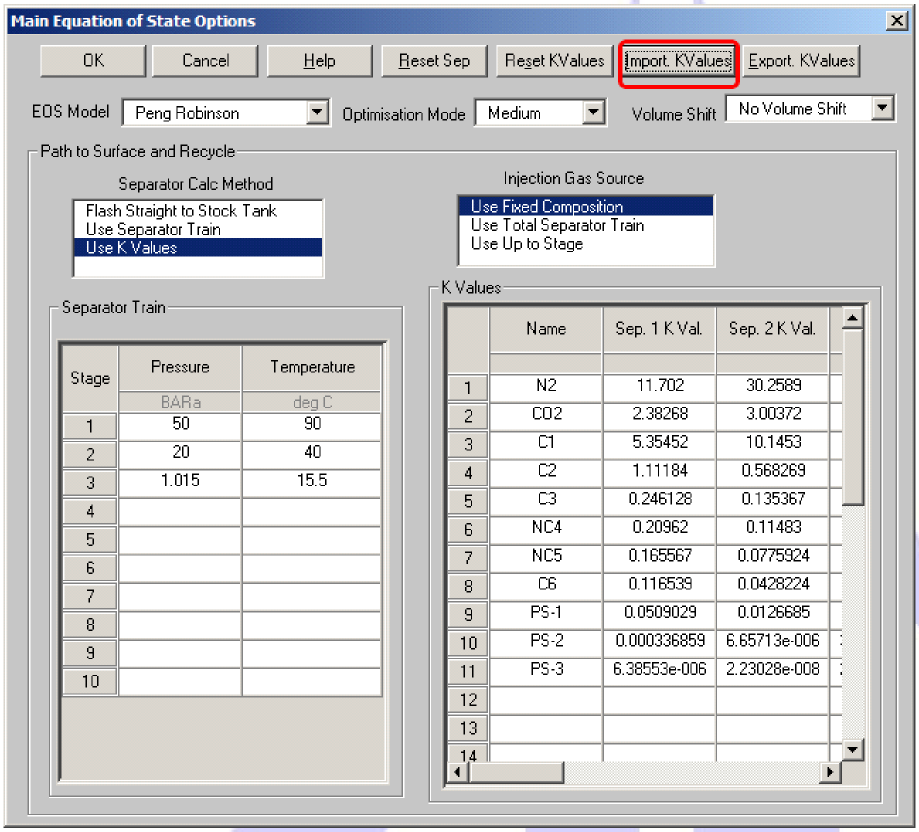
Select Type of K Value to Export

● Individual Separator stage K Values

○ One set of K Values to represent all stages

Select Destination for K Values

Now the program will allow the user to export a *.pks file than can be imported in **MBAL**, containing all of the information with respect to separator stages and K values.


Main Equation of State Options
OK
Cancel
Help
Reset Sep
Reset KValues
Import. KValues
Export. KValues
Path to Surface and Recycle
Separator Calc Method
Flash Straight to Stock Tank
Use Separator Train
Use K Values
Injection Gas Source
Use Fixed Composition
Use Total Separator Train
Use Up to Stage
Separator Train
K Values

EOS Model: Peng Robinson

Optimisation Mode: Medium

Volume Shift: No Volume Shift

Separator Calc Method: Use K Values

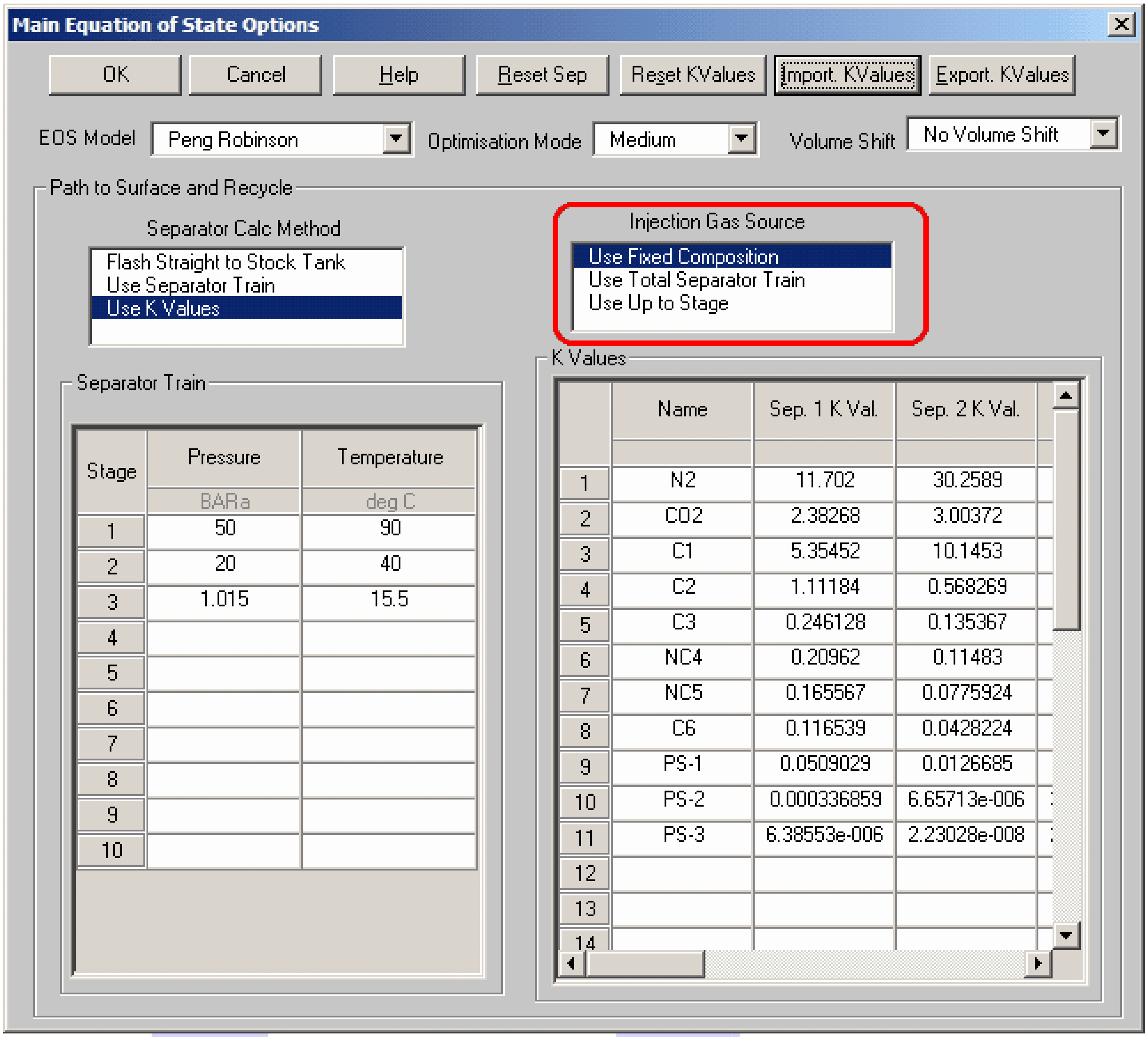
Injection Gas Source: Use Fixed Composition

Stage	Pressure	Temperature
	BARa	deg C
1	50	90
2	20	40
3	1.015	15.5
4		
5		
6		
7		
8		
9		
10		

	Name	Sep. 1 K Val.	Sep. 2 K Val.
1	N2	11.702	30.2589
2	CO2	2.38268	3.00372
3	C1	5.35452	10.1453
4	C2	1.11184	0.568269
5	C3	0.246128	0.135367
6	NC4	0.20962	0.11483
7	NC5	0.165567	0.0775924
8	C6	0.116539	0.0428224
9	PS-1	0.0509029	0.0126685
10	PS-2	0.000336859	6.65713e-006
11	PS-3	6.38553e-006	2.23028e-008
12			
13			
14			

2.3.4.3.1.4 Injection Gas Source

These options define the properties of the gas to be possibly injected in the reservoir:


Main Equation of State Options
OK
Cancel
Help
Reset Sep
Reset KValues
Import. KValues
Export. KValues
Path to Surface and Recycle

EOS Model: Peng Robinson

Optimisation Mode: Medium

Volume Shift: No Volume Shift

Separator Calc Method

- Flash Straight to Stock Tank
- Use Separator Train
- Use K Values

Injection Gas Source

- Use Fixed Composition
- Use Total Separator Train
- Use Up to Stage

Separator Train

Stage	Pressure BARa	Temperature deg C
1	50	90
2	20	40
3	1.015	15.5
4		
5		
6		
7		
8		
9		
10		

K Values

	Name	Sep. 1 K Val.	Sep. 2 K Val.
1	N2	11.702	30.2589
2	CO2	2.38268	3.00372
3	C1	5.35452	10.1453
4	C2	1.11184	0.568269
5	C3	0.246128	0.135367
6	NC4	0.20962	0.11483
7	NC5	0.165567	0.0775924
8	C6	0.116539	0.0428224
9	PS-1	0.0509029	0.0126685
10	PS-2	0.000336859	6.65713e-006
11	PS-3	6.38553e-006	2.23028e-008
12			
13			
14			

The three available options will either use a fixed composition which can be defined later, the gas resulting from a given separation process or the gas which can be picked from a selected number of separator stages.

2.3.4.3.2 Compositional Tracking

The material balance tool allows compositional tracking in both history simulation and production prediction.

Input Data

To use compositional tracking the following input data must be entered.

- Select the *Options* menu and select the *Yes* option in the *Compositional Tracking* combo box.
- Next enter the composition of the tanks at the start of the production history (or at the start of the prediction if there is no production history). Select the *PVT* menu and *Oil Composition* and *Gas Composition*.
- The composition of the free oil and the composition of the free gas at this time are required as input data. If a gas or condensate system is in use, then there is no free oil in the tank - in this case, enter the gas composition in both the oil and gas composition dialogue. Conversely, if an oil system above the bubble point has been defined, there is no free gas - in this case enter the oil composition in both the oil and gas composition dialogue. Note that the same input composition is used for all tanks in a multi-tank system.
- If gas injection, gas recycling or gas voidage replacement are to be accounted for, the composition of the gas being injected into the tank needs to be defined. Select the *PVT* menu and *Gas Injection Composition*.

All the input compositions for a particular data set must have the same number of components and the same component names. If a component is to be excluded from a particular composition then enter a very small fraction (i.e. 1.0e-06) - note that it is not valid to enter a fraction of 0.0.

The input data for history simulation or production prediction must also be entered as normal.

Operation

If all this input data has been successfully entered, **MBAL** is ready to do compositional tracking.

Re-running a simulation or a production prediction as normal will now calculate the composition of the free oil, the free gas and the combined composition (of the free oil and gas) in each tank at each time step.

To view the tank results for the history simulation, select the *History Matching-Run Simulation* menu item. The mole fraction of each component is displayed as an extra column to the far right or the results table. For more detailed results, click on the analysis button for a particular row - It will now be possible to view the free oil composition, free gas composition and total composition as well as generate fluid properties and plot the phase envelope.

The tank results for a production prediction are in the same form but the *Production Prediction-Run Prediction* menu item must be accessed.

Having performed a production prediction with prediction wells, **MBAL** will also calculate the compositions from each layer and the combined well compositions. To view the well/layer results, select the *Production Prediction--Well Results* menu item. The results are accessed as for the tank results.

What is MBAL Calculating?

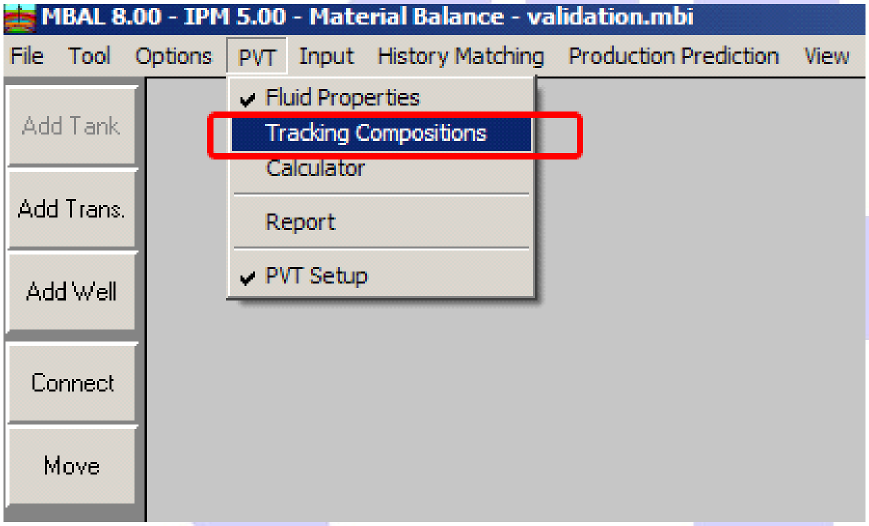
The first important thing to note is that this calculation is effectively a post processor. The standard simulation/prediction results such as pressure, rates, saturations will be exactly the same whether compositional tracking is on or off. This is because **MBAL** does not use the composition to calculated the required fluid properties at each time step - it uses the standard black oil models.

So what does **MBAL** actually calculate?

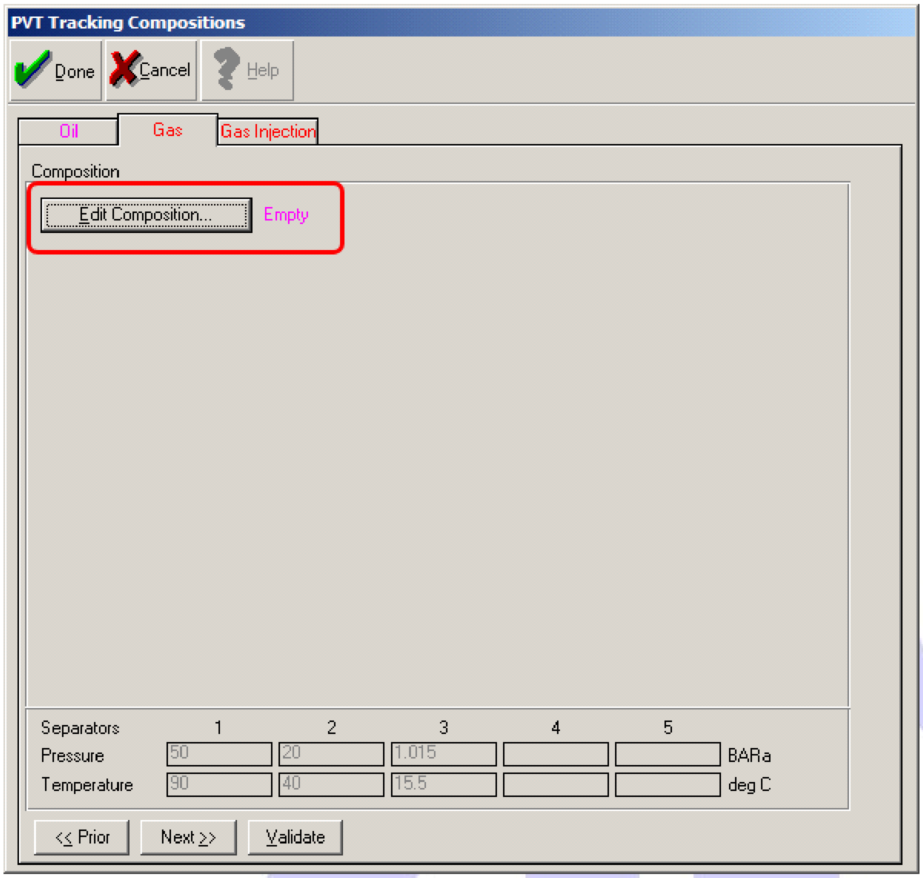
- At the start of the time step, **MBAL** calculates the well and layer compositions using the well and layer rates plus the composition in the tank at that time.
- **MBAL** then calculates the pressure and the new volumes at the end of the time step as normal.
- The composition at the start of the time step is then flashed to the new pressure at the end of the time step.
- Using the new volumes of oil and gas at the end of the time step and the new oil and gas composition, **MBAL** can calculate a new total composition.
- These new compositions are then used as input to the next time step and so on...

Example set up

Once the compositional tracking option is selected and the EOS setup complete, the PVT button will show an option to enter the compositions for tracking:


MBAL 8.00 - IPM 5.00 - Material Balance - validation.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
✓ Fluid Properties
Tracking Compositions
Calculator
Report
✓ PVT Setup
Add Tank
Add Trans.
Add Well
Connect
Move

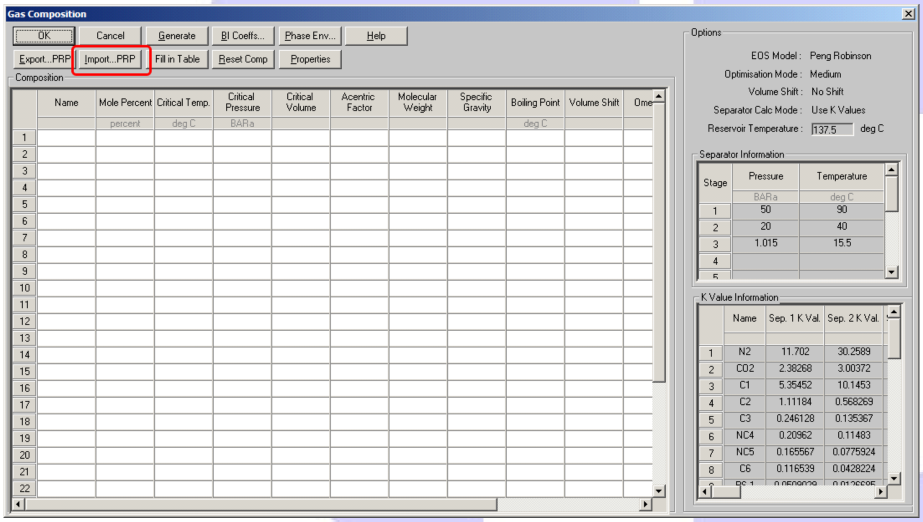
In this screen:


PVT Tracking Compositions
Done
Cancel
Help
Oil
Gas
Gas Injection
Composition
Edit Composition...
<< Prior
Next >>
Validate

Empty

Separators	1	2	3	4	5	
Pressure	50	20	1.015			BARa
Temperature	90	40	15.5			deg C

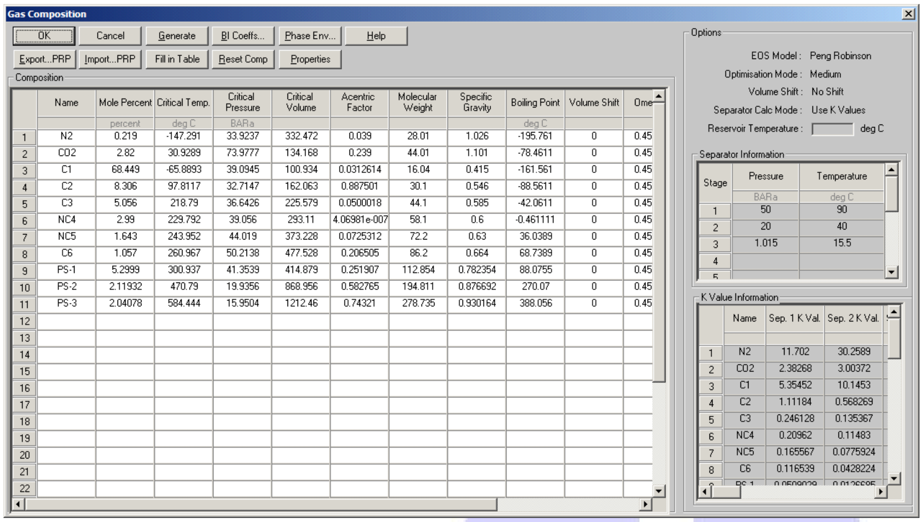
The “Edit Composition” will allow the import of the EOS for this fluid to be carried out:


Gas Composition
OK
Cancel
Generate
BI Coeffs...
Phase Env...
Help
Export...PRP
Import...PRP
Fill in Table
Reset Comp
Properties
Composition
Name
Mole Percent
Critical Temp.
Critical Pressure
Critical Volume
Acentric Factor
Molecular Weight
Specific Gravity
Boiling Point
Volume Shift
Ome
percent
deg C
BARa
deg C
Options
Separator Information
K Value Information

EOS Model : Peng Robinson
Optimisation Mode : Medium
Volume Shift : No Shift
Separator Calc Mode : Use K Values
Reservoir Temperature : 137.5 deg C

Stage	Pressure (BARa)	Temperature (deg C)
1	50	90
2	20	40
3	1.015	15.5
4		

	Name	Sep. 1 K Val.	Sep. 2 K Val.
1	N2	11.702	30.2589
2	CO2	2.38268	3.00372
3	C1	5.35452	10.1453
4	C2	1.11184	0.568269
5	C3	0.246128	0.135367
6	NC4	0.20962	0.11483
7	NC5	0.165567	0.0775924
8	C6	0.116539	0.0428224



	Name	Mole Percent	Critical Temp.	Critical Pressure	Critical Volume	Acentric Factor	Molecular Weight	Specific Gravity	Boiling Point	Volume Shift	Ome
		percent	deg C	BARa					deg C		
1	N2	0.219	-147.291	33.9237	332.472	0.039	28.01	1.026	-195.761	0	0.45
2	CO2	2.82	30.9289	73.9777	134.168	0.239	44.01	1.101	-78.4611	0	0.45
3	C1	68.449	-65.8893	39.0945	100.934	0.0312614	16.04	0.415	-161.561	0	0.45
4	C2	8.306	97.8117	32.7147	162.063	0.887501	30.1	0.546	-88.5611	0	0.45
5	C3	5.056	218.79	36.6426	225.579	0.0500018	44.1	0.585	-42.0611	0	0.45
6	NC4	2.99	229.792	39.056	293.11	4.06981e-007	58.1	0.6	-0.461111	0	0.45
7	NC5	1.643	243.952	44.019	373.228	0.0725312	72.2	0.63	36.0389	0	0.45
8	C6	1.057	260.967	50.2138	477.528	0.206505	86.2	0.664	68.7389	0	0.45
9	PS-1	5.2999	300.937	41.3539	414.879	0.251907	112.854	0.782354	88.0755	0	0.45
10	PS-2	2.11932	470.79	19.9356	868.956	0.582765	194.811	0.876692	270.07	0	0.45
11	PS-3	2.04078	584.444	15.9504	1212.46	0.74321	278.735	0.930164	388.056	0	0.45

Options

EOS Model : Peng Robinson
Optimisation Mode : Medium
Volume Shift : No Shift
Separator Calc Mode : Use K Values
Reservoir Temperature : deg C

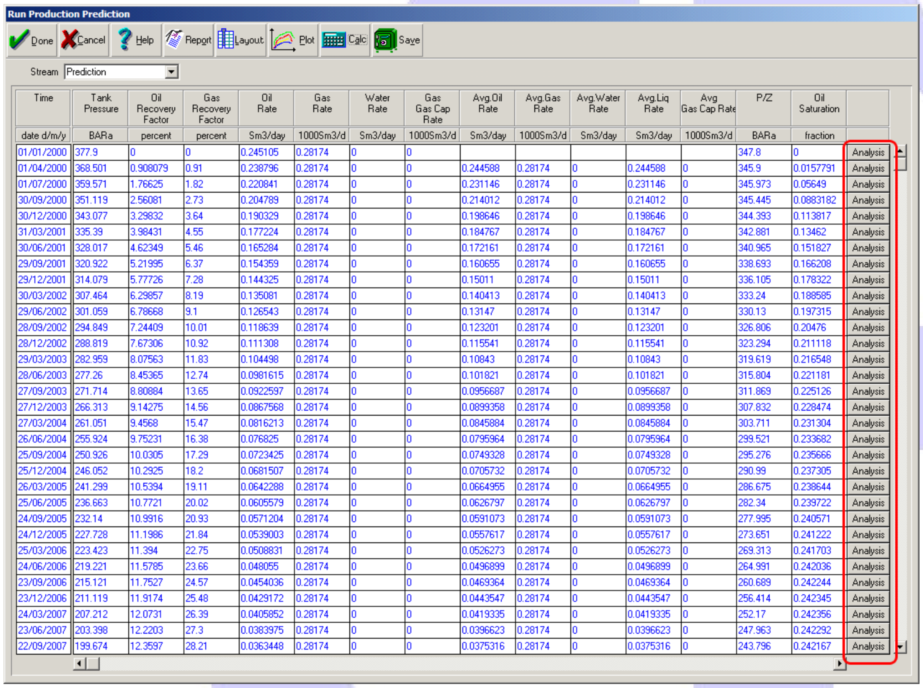
Separator Information

Stage	Pressure	Temperature
	BARa	deg C
1	50	90
2	20	40
3	1.015	15.5
4		

K Value Information

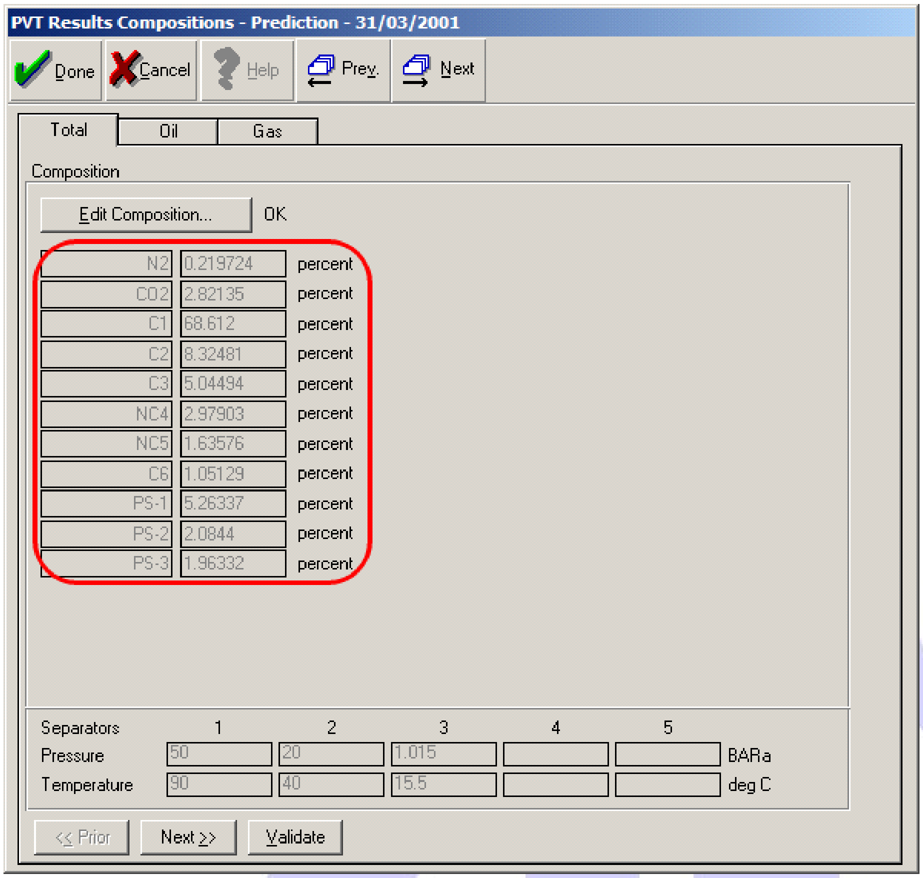
	Name	Sep. 1 K Val.	Sep. 2 K Val.
1	N2	11.702	30.2589
2	CO2	2.38268	3.00372
3	C1	5.35452	10.1453
4	C2	1.11184	0.568269
5	C3	0.246128	0.135367
6	NC4	0.20962	0.11483
7	NC5	0.165567	0.0775924
8	C6	0.116539	0.0428224

Once a prediction is carried out, one extra button will appear in the results screen (the “Analysis” button), this allows the variation of composition in time to be viewed:



Stream Prediction

Time	Tank Pressure	Oil Recovery Factor	Gas Recovery Factor	Oil Rate	Gas Rate	Water Rate	Gas Gas Cap Rate	Avg.Oil Rate	Avg.Gas Rate	Avg.Water Rate	Avg.Liq Rate	Avg Gas Cap Rate	P/Z	Oil Saturation	
date d/m/y	BARa	percent	percent	Sm3/day	1000Sm3/d	Sm3/day	1000Sm3/d	Sm3/day	1000Sm3/d	Sm3/day	Sm3/day	1000Sm3/d	BARa	fraction	
01/01/2000	377.9	0	0	0.245105	0.28174	0	0						347.8	0	Analysis
01/04/2000	368.501	0.908079	0.91	0.238796	0.28174	0	0	0.244588	0.28174	0	0.244588	0	345.9	0.0157791	Analysis
01/07/2000	359.571	1.76625	1.82	0.220841	0.28174	0	0	0.231146	0.28174	0	0.231146	0	345.973	0.05649	Analysis
30/09/2000	351.119	2.56081	2.73	0.204789	0.28174	0	0	0.214012	0.28174	0	0.214012	0	345.445	0.0883182	Analysis
30/12/2000	343.077	3.29832	3.64	0.190329	0.28174	0	0	0.198646	0.28174	0	0.198646	0	344.393	0.113817	Analysis
31/03/2001	335.39	3.98431	4.55	0.177224	0.28174	0	0	0.184767	0.28174	0	0.184767	0	342.881	0.13462	Analysis
30/06/2001	328.017	4.62349	5.46	0.165284	0.28174	0	0	0.172161	0.28174	0	0.172161	0	340.965	0.151827	Analysis
29/09/2001	320.922	5.21995	6.37	0.154359	0.28174	0	0	0.160655	0.28174	0	0.160655	0	338.693	0.166208	Analysis
29/12/2001	314.079	5.77726	7.28	0.144325	0.28174	0	0	0.15011	0.28174	0	0.15011	0	336.105	0.178322	Analysis
30/03/2002	307.464	6.29857	8.19	0.135081	0.28174	0	0	0.140413	0.28174	0	0.140413	0	333.24	0.188585	Analysis
29/06/2002	301.059	6.78668	9.1	0.126543	0.28174	0	0	0.13147	0.28174	0	0.13147	0	330.13	0.197315	Analysis
28/09/2002	294.849	7.24409	10.01	0.118639	0.28174	0	0	0.123201	0.28174	0	0.123201	0	326.806	0.20476	Analysis
28/12/2002	288.819	7.67306	10.92	0.111308	0.28174	0	0	0.115541	0.28174	0	0.115541	0	323.294	0.211118	Analysis
29/03/2003	282.959	8.07563	11.83	0.104498	0.28174	0	0	0.10843	0.28174	0	0.10843	0	319.619	0.216548	Analysis
28/06/2003	277.26	8.45365	12.74	0.0981615	0.28174	0	0	0.101821	0.28174	0	0.101821	0	315.804	0.221181	Analysis
27/09/2003	271.714	8.80884	13.65	0.0922597	0.28174	0	0	0.0956687	0.28174	0	0.0956687	0	311.869	0.225126	Analysis
27/12/2003	266.313	9.14275	14.56	0.0867568	0.28174	0	0	0.0899358	0.28174	0	0.0899358	0	307.832	0.228474	Analysis
27/03/2004	261.051	9.4568	15.47	0.0816213	0.28174	0	0	0.0845884	0.28174	0	0.0845884	0	303.711	0.231304	Analysis
26/06/2004	255.924	9.75231	16.38	0.076825	0.28174	0	0	0.0795964	0.28174	0	0.0795964	0	299.521	0.233682	Analysis
25/09/2004	250.926	10.0305	17.29	0.0723425	0.28174	0	0	0.0749328	0.28174	0	0.0749328	0	295.276	0.235666	Analysis
25/12/2004	246.052	10.2925	18.2	0.0681507	0.28174	0	0	0.0705732	0.28174	0	0.0705732	0	290.99	0.237305	Analysis
26/03/2005	241.299	10.5394	19.11	0.0642288	0.28174	0	0	0.0664955	0.28174	0	0.0664955	0	286.675	0.238644	Analysis
25/06/2005	236.663	10.7721	20.02	0.0605579	0.28174	0	0	0.0626797	0.28174	0	0.0626797	0	282.34	0.239722	Analysis
24/09/2005	232.14	10.9916	20.93	0.0571204	0.28174	0	0	0.0591073	0.28174	0	0.0591073	0	277.995	0.240571	Analysis
24/12/2005	227.728	11.1986	21.84	0.0539003	0.28174	0	0	0.0557617	0.28174	0	0.0557617	0	273.651	0.241222	Analysis
25/03/2006	223.423	11.394	22.75	0.0508831	0.28174	0	0	0.0526273	0.28174	0	0.0526273	0	269.313	0.241703	Analysis
24/06/2006	219.221	11.5785	23.66	0.048055	0.28174	0	0	0.0496899	0.28174	0	0.0496899	0	264.991	0.242036	Analysis
23/09/2006	215.121	11.7527	24.57	0.0454036	0.28174	0	0	0.0469364	0.28174	0	0.0469364	0	260.689	0.242244	Analysis
23/12/2006	211.119	11.9174	25.48	0.0429172	0.28174	0	0	0.0443547	0.28174	0	0.0443547	0	256.414	0.242345	Analysis
24/03/2007	207.212	12.0731	26.39	0.0405852	0.28174	0	0	0.0419335	0.28174	0	0.0419335	0	252.17	0.242356	Analysis
23/06/2007	203.398	12.2203	27.3	0.0383975	0.28174	0	0	0.0396623	0.28174	0	0.0396623	0	247.963	0.242292	Analysis
22/09/2007	199.674	12.3597	28.21	0.0363448	0.28174	0	0	0.0375316	0.28174	0	0.0375316	0	243.796	0.242167	Analysis



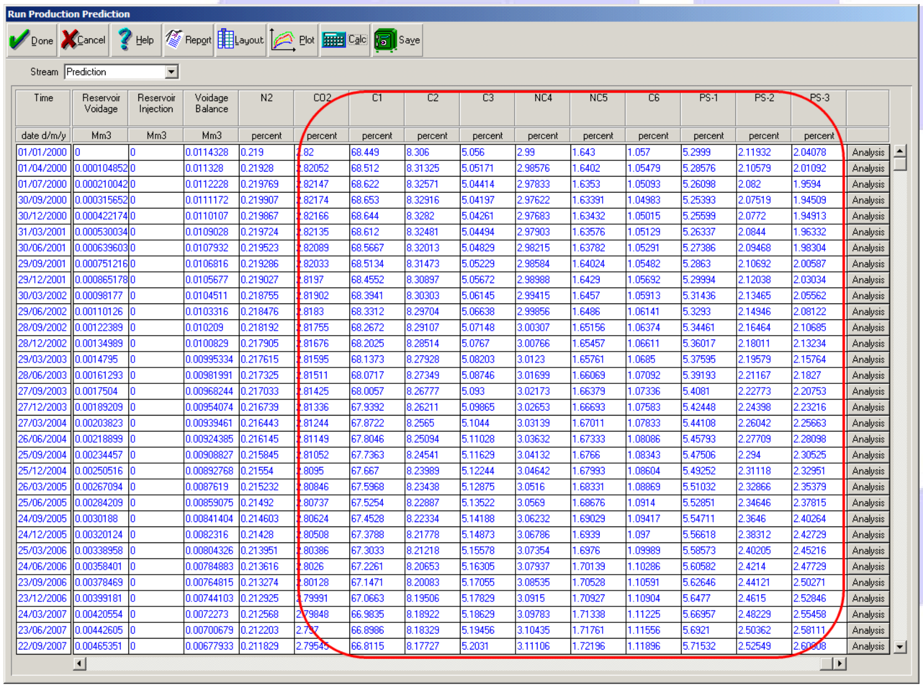
Composition

OK

N2	0.219724	percent
CO2	2.82135	percent
C1	68.612	percent
C2	8.32481	percent
C3	5.04494	percent
NC4	2.97903	percent
NC5	1.63576	percent
C6	1.05129	percent
PS-1	5.26337	percent
PS-2	2.0844	percent
PS-3	1.96332	percent

Separators	1	2	3	4	5	
Pressure	50	20	1.015			BARa
Temperature	90	40	15.5			deg C

Of course the results can also be seen and plotted from the results screen itself:



Stream: Prediction

Time	Reservoir Voidage	Reservoir Injection	Voidage Balance	N2	CO2	C1	C2	C3	NC4	NC5	C6	PS-1	PS-2	PS-3	
date d/m/y	Mm3	Mm3	Mm3	percent	percent	percent	percent	percent	percent	percent	percent	percent	percent	percent	
01/01/2000	0	0	0.0114328	0.219	2.82	68.449	8.306	5.056	2.99	1.643	1.057	5.2999	2.11932	2.04078	Analysis
01/04/2000	0.000104852	0	0.011328	0.21928	2.82052	68.512	8.31325	5.05171	2.98576	1.6402	1.05479	5.28576	2.10579	2.01092	Analysis
01/07/2000	0.000210042	0	0.0112228	0.219769	2.82147	68.622	8.32571	5.04414	2.97833	1.6353	1.05093	5.26098	2.082	1.9594	Analysis
30/09/2000	0.000315652	0	0.0111172	0.219907	2.82174	68.653	8.32916	5.04197	2.97622	1.63391	1.04983	5.25393	2.07519	1.94509	Analysis
30/12/2000	0.000422174	0	0.0110107	0.219867	2.82166	68.644	8.3282	5.04261	2.97683	1.63432	1.05015	5.25599	2.0772	1.94913	Analysis
31/03/2001	0.000530034	0	0.0109028	0.219724	2.82135	68.612	8.32481	5.04494	2.97903	1.63576	1.05129	5.26337	2.0844	1.96332	Analysis
30/06/2001	0.000639603	0	0.0107932	0.219523	2.82089	68.5667	8.32013	5.04829	2.98215	1.63782	1.05291	5.27386	2.09468	1.98304	Analysis
29/09/2001	0.000751216	0	0.0106816	0.219286	2.82033	68.5134	8.31473	5.05229	2.98584	1.64024	1.05482	5.2863	2.10692	2.00587	Analysis
29/12/2001	0.000865178	0	0.0105677	0.219027	2.8197	68.4552	8.30897	5.05672	2.98988	1.6429	1.05692	5.29994	2.12038	2.03034	Analysis
30/03/2002	0.00098177	0	0.0104511	0.218755	2.81902	68.3941	8.30303	5.06145	2.99415	1.6457	1.05913	5.31436	2.13465	2.05562	Analysis
29/06/2002	0.00110126	0	0.0103316	0.218476	2.8183	68.3312	8.29704	5.06638	2.99856	1.6486	1.06141	5.3293	2.14946	2.08122	Analysis
28/09/2002	0.00122389	0	0.010209	0.218192	2.81755	68.2672	8.29107	5.07148	3.00307	1.65156	1.06374	5.34461	2.16464	2.10685	Analysis
28/12/2002	0.00134989	0	0.0100829	0.217905	2.81676	68.2025	8.28514	5.0767	3.00766	1.65457	1.06611	5.36017	2.18011	2.13234	Analysis
29/03/2003	0.0014795	0	0.00995334	0.217615	2.81595	68.1373	8.27928	5.08203	3.0123	1.65761	1.0685	5.37595	2.19579	2.15764	Analysis
28/06/2003	0.00161293	0	0.00981991	0.217325	2.81511	68.0717	8.27349	5.08746	3.01699	1.66069	1.07092	5.39193	2.21167	2.1827	Analysis
27/09/2003	0.0017504	0	0.00968244	0.217033	2.81425	68.0057	8.26777	5.093	3.02173	1.66379	1.07336	5.4081	2.22773	2.20753	Analysis
27/12/2003	0.00189209	0	0.00954074	0.216739	2.81336	67.9392	8.26211	5.09865	3.02653	1.66693	1.07583	5.42448	2.24398	2.23216	Analysis
27/03/2004	0.00203823	0	0.00939461	0.216443	2.81244	67.8722	8.2565	5.1044	3.03139	1.67011	1.07833	5.44108	2.26042	2.25663	Analysis
26/06/2004	0.00218899	0	0.00924385	0.216145	2.81149	67.8046	8.25094	5.11028	3.03632	1.67333	1.08086	5.45793	2.27709	2.28098	Analysis
25/09/2004	0.00234457	0	0.00908827	0.215845	2.81052	67.7363	8.24541	5.11629	3.04132	1.6766	1.08343	5.47506	2.294	2.30525	Analysis
25/12/2004	0.00250516	0	0.00892768	0.21554	2.8095	67.667	8.23989	5.12244	3.04642	1.67993	1.08604	5.49252	2.31118	2.32951	Analysis
26/03/2005	0.00267094	0	0.0087619	0.215232	2.80846	67.5968	8.23438	5.12875	3.0516	1.68331	1.08869	5.51032	2.32866	2.35379	Analysis
25/06/2005	0.00284209	0	0.00859075	0.21492	2.80737	67.5254	8.22887	5.13522	3.0569	1.68676	1.0914	5.52851	2.34646	2.37815	Analysis
24/09/2005	0.0030188	0	0.00841404	0.214603	2.80624	67.4528	8.22334	5.14188	3.06232	1.69029	1.09417	5.54711	2.3646	2.40264	Analysis
24/12/2005	0.00320124	0	0.0082316	0.21428	2.80508	67.3788	8.21778	5.14873	3.06786	1.6939	1.097	5.56618	2.38312	2.42729	Analysis
25/03/2006	0.00338958	0	0.00804326	0.213951	2.80386	67.3033	8.21218	5.15578	3.07354	1.6976	1.09989	5.58573	2.40205	2.45216	Analysis
24/06/2006	0.00358401	0	0.00784883	0.213616	2.8026	67.2261	8.20653	5.16305	3.07937	1.70139	1.10286	5.60582	2.4214	2.47729	Analysis
23/09/2006	0.00378469	0	0.00764815	0.213274	2.80128	67.1471	8.20083	5.17055	3.08535	1.70528	1.10591	5.62646	2.44121	2.50271	Analysis
23/12/2006	0.00399181	0	0.00744103	0.212925	2.79991	67.0663	8.19506	5.17829	3.0915	1.70927	1.10904	5.6477	2.4615	2.52846	Analysis
24/03/2007	0.00420554	0	0.0072273	0.212568	2.79848	66.9835	8.18922	5.18629	3.09783	1.71338	1.11225	5.66957	2.48229	2.55458	Analysis
23/06/2007	0.00442605	0	0.00700679	0.212203	2.797	66.8986	8.18329	5.19456	3.10435	1.71761	1.11556	5.6921	2.50362	2.58111	Analysis
22/09/2007	0.00465351	0	0.00677933	0.211829	2.79545	66.8115	8.17727	5.2031	3.11106	1.72196	1.11896	5.71532	2.52549	2.60808	Analysis

2.3.4.3.3 Fully Compositional fluid description

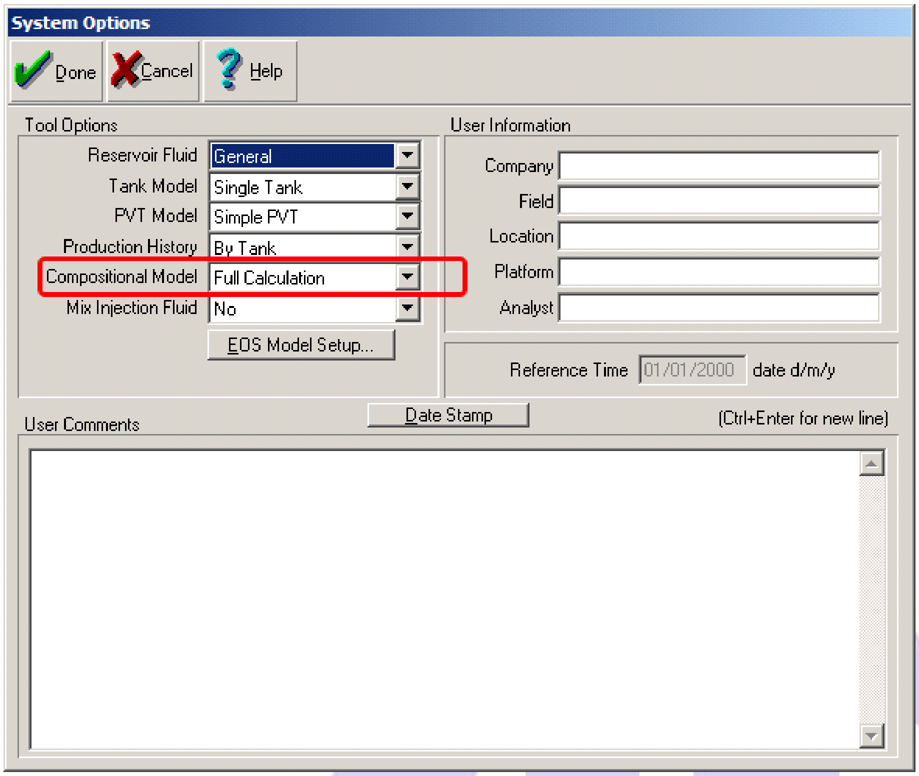
This method allows for an equation of state to be used when modelling the fluid behaviour with respect to changing pressures and temperatures. So this method allows the tracking of the number of moles in the reservoir rather than surface volumes to be carried out. The process can be described as follows:

- Calculate the initial number of moles in the tank from the initial surface volume, the gravities and molecular weights at surface calculated from flashing the initial composition to surface.
- At each time step:
  - Calculate the well performance, the program will use the black oil properties for this calculation, taken from flashing the current reservoir composition.
  - Calculate the number of moles in the production over the time step using the gravities and molecular weights at surface calculated from the last flash.
  - Remove these moles from the tank.
  - Use flash to calculate the number of moles in each phase and the oil and gas composition at the current pressure.
  - Calculate the downhole volume of each phase using the molecular weight and density calculated from the flash at the current pressure.

Different compositions moving between tanks using transmissibilities are also modelled, at the same time different injection compositions are also taken in to account.

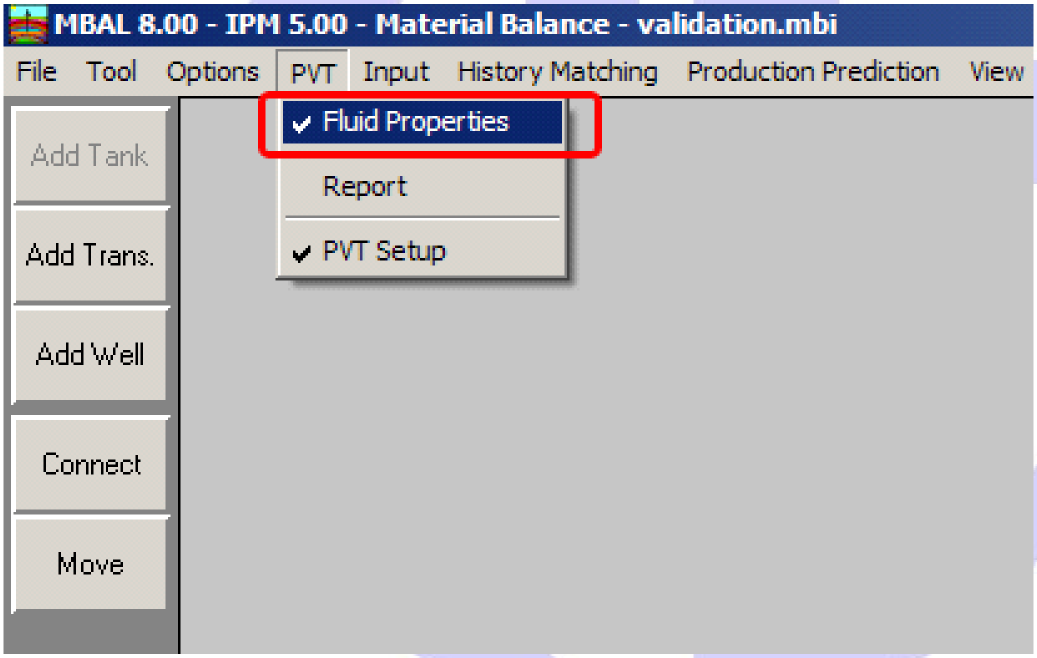
Graphical plots are based on CCE (constant composition expansion) theory; therefore it is assumed this experiment only in the plots. Analytic plots, history regression and history simulation respect the actual process.

Once the 'Fully Compositional' option is selected and the EOS setup completed:

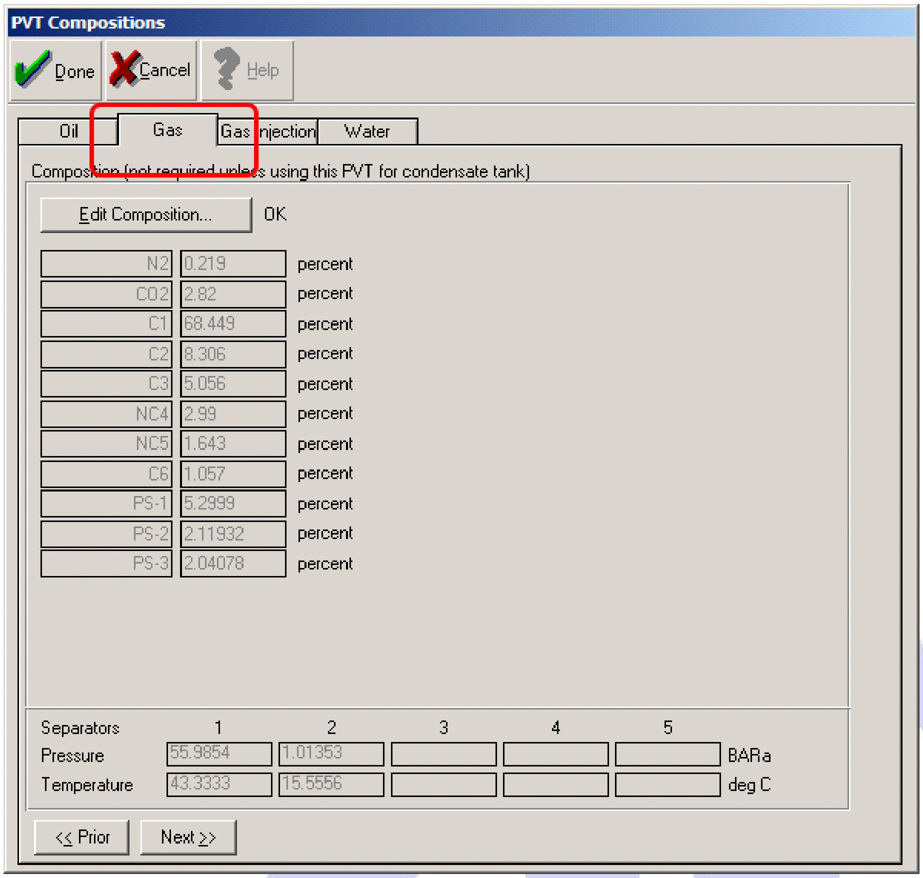

System Options
Done
Cancel
Help
Tool Options
User Information
EOS Model Setup...
Date Stamp
User Comments
(Ctrl+Enter for new line)

Reservoir Fluid: General
Tank Model: Single Tank
PVT Model: Simple PVT
Production History: By Tank
Compositional Model: Full Calculation
Mix Injection Fluid: No
Company
Field
Location
Platform
Analyst
Reference Time: 01/01/2000 date d/m/y

The PVT button will show an option to enter the compositions for tracking:


MBAL 8.00 - IPM 5.00 - Material Balance - validation.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
✓ Fluid Properties
Report
✓ PVT Setup
Add Tank
Add Trans.
Add Well
Connect
Move

In this screen:


PVT Compositions
Done
Cancel
Help
Oil
Gas
Gas Injection
Water
Edit Composition...
<< Prior
Next >>

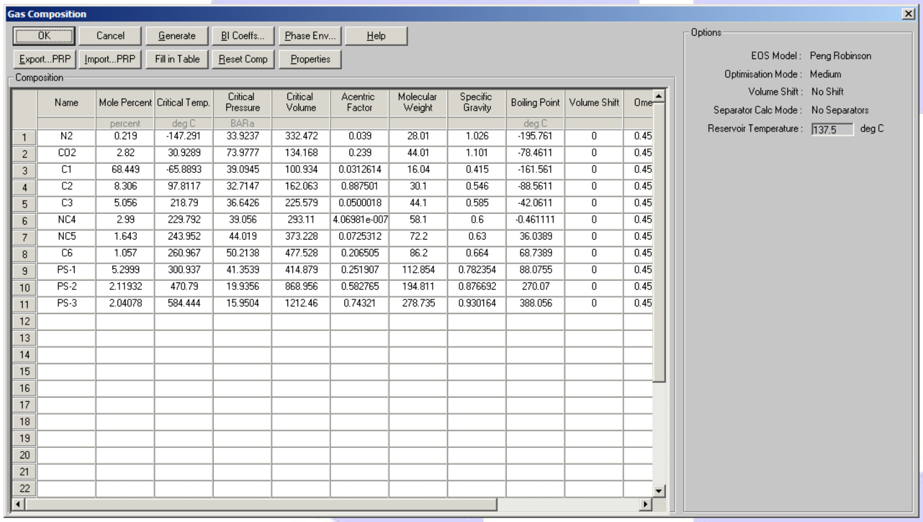
Composition (not required unless using this PVT for condensate tank)

OK

N2	0.219	percent
CO2	2.82	percent
C1	68.449	percent
C2	8.306	percent
C3	5.056	percent
NC4	2.99	percent
NC5	1.643	percent
C6	1.057	percent
PS-1	5.2999	percent
PS-2	2.11932	percent
PS-3	2.04078	percent

Separators	1	2	3	4	5	
Pressure	55.9854	1.01353				BARa
Temperature	43.3333	15.5556				deg C

The equation of state for each fluid in the system can be entered separately:


Gas Composition
OK
Cancel
Generate
BI Coeffs...
Phase Env...
Help
Export...PRP
Import...PRP
Fill in Table
Reset Comp
Properties
Composition
Options

	Name	Mole Percent	Critical Temp.	Critical Pressure	Critical Volume	Acentric Factor	Molecular Weight	Specific Gravity	Boiling Point	Volume Shift	Ome
		percent	deg C	BARa					deg C		
1	N2	0.219	-147.291	33.9237	332.472	0.039	28.01	1.026	-195.761	0	0.45
2	CO2	2.82	30.9289	73.9777	134.168	0.239	44.01	1.101	-78.4611	0	0.45
3	C1	68.449	-65.8893	39.0945	100.934	0.0312614	16.04	0.415	-161.561	0	0.45
4	C2	8.306	97.8117	32.7147	162.063	0.887501	30.1	0.546	-88.5611	0	0.45
5	C3	5.056	218.79	36.6426	225.579	0.0500018	44.1	0.585	-42.0611	0	0.45
6	NC4	2.99	229.792	39.056	293.11	4.06981e-007	58.1	0.6	-0.461111	0	0.45
7	NC5	1.643	243.952	44.019	373.228	0.0725312	72.2	0.63	36.0389	0	0.45
8	C6	1.057	260.967	50.2138	477.528	0.206505	86.2	0.664	68.7389	0	0.45
9	PS-1	5.2999	300.937	41.3539	414.879	0.251907	112.854	0.782354	88.0755	0	0.45
10	PS-2	2.11932	470.79	19.9356	868.956	0.582765	194.811	0.876692	270.07	0	0.45
11	PS-3	2.04078	584.444	15.9504	1212.46	0.74321	278.735	0.930164	388.056	0	0.45
12											
13											
14											
15											
16											
17											
18											
19											
20											
21											
22											

EOS Model : Peng Robinson
Optimisation Mode : Medium
Volume Shift : No Shift
Separator Calc Mode : No Separators
Reservoir Temperature : 137.5 deg C

The import can be done in the same way as shown earlier.

The results can be viewed in the same way as for the compositional tracking option.

2.3.4.3.3.1 Lumping/Delumping

Lumping/Delumping allows the number of components for the fluid composition to be extended or reduced while maintaining the fluid properties.

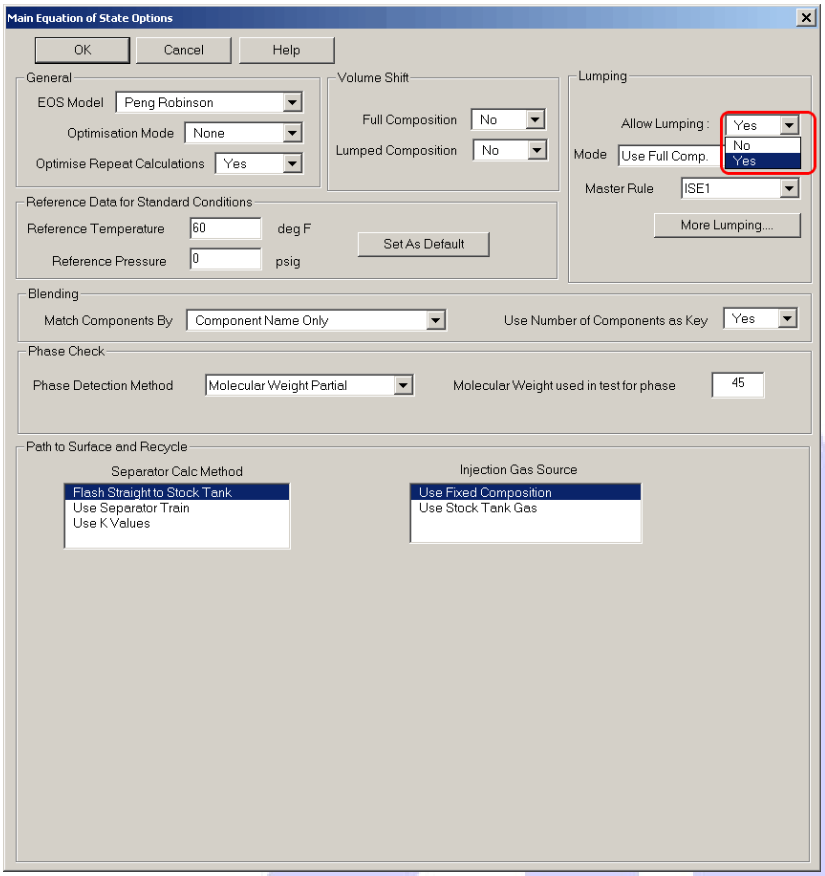
MBAL is part of the **IPM** suite; as such, it is a part of a set of tools allowing for a fully integrated system which can dynamically model the behaviour of the fluid from the reservoir through to the processing system.

This means that the modelled fluid throughout the system needs to correspond to the necessary information in the necessary format required by the processing model.

Evidently, the fluid PVT and characterisation must be the same across the whole model (ensure that the same is fluid is being modelled). The concept behind compositional lumping/delumping is to be able to pass from an extended composition (full/delumped) to a reduced one and vice-versa without impacting on the quality of the characterisation, this means that at any point, full and lumped compositions will be equivalent and representative of the real fluid.

How the fluid is to be lumped is pre-defined during the characterisation of the fluid in PVTP. This characterised fluid can then be imported as previously described and **MBAL** will automatically account for the defined lumping 'Rule.'

The observance of the 'Rule' can be verified in **MBAL**:


Main Equation of State Options
OK
Cancel
Help
General
Volume Shift
Lumping
Reference Data for Standard Conditions
Set As Default
More Lumping....
Blending
Phase Check
Path to Surface and Recycle

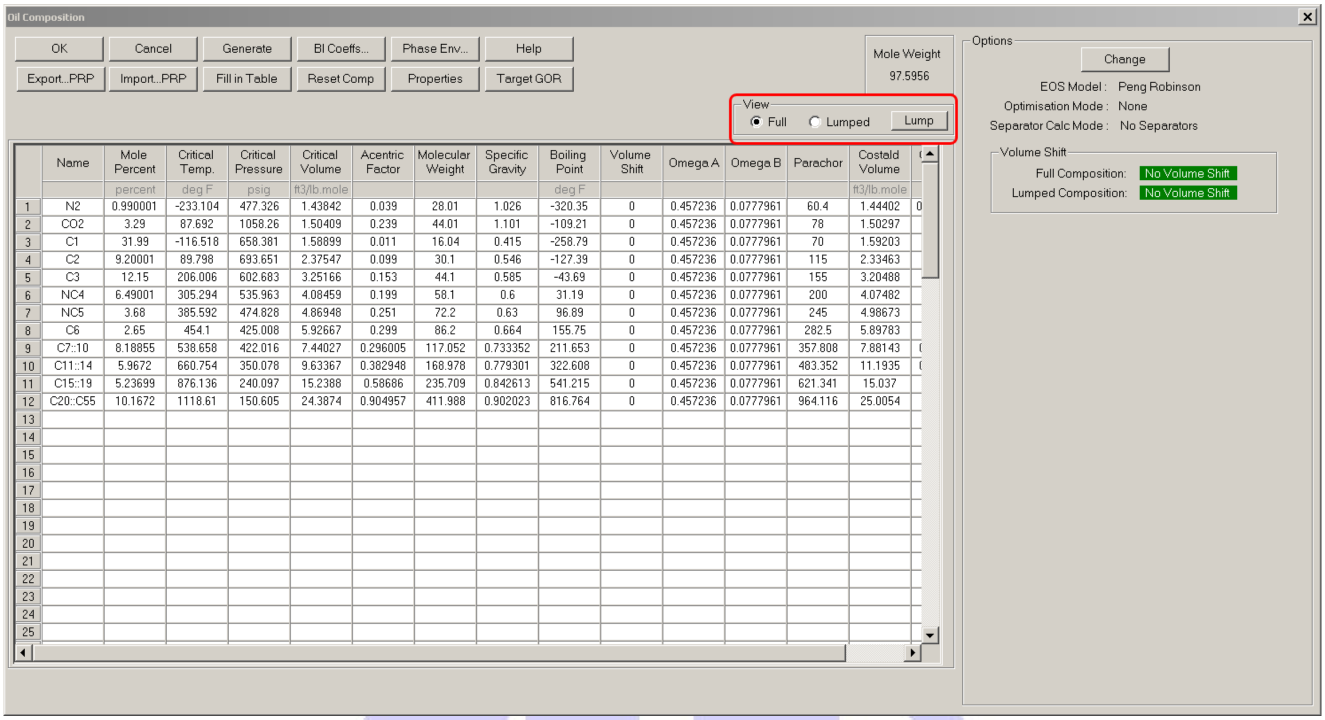
EOS Model: Peng Robinson
Optimisation Mode: None
Optimise Repeat Calculations: Yes
Full Composition: No
Lumped Composition: No
Allow Lumping : Yes
No
Yes
Mode: Use Full Comp.
Master Rule: ISE1
Reference Temperature: 60 deg F
Reference Pressure: 0 psig
Match Components By: Component Name Only
Use Number of Components as Key: Yes
Phase Detection Method: Molecular Weight Partial
Molecular Weight used in test for phase: 45

Separator Calc Method
- Flash Straight to Stock Tank
- Use Separator Train
- Use K Values

Injection Gas Source
- Use Fixed Composition
- Use Stock Tank Gas

Ensuring that the 'Allow Lumping' option has been set to yes, the 'Rule' defined during the characterisation will be accounted for.

When entering the fluid PVT as described in the 'Help,' the full fluid composition will be seen, and an option to view either 'Full' or 'Lumped' description can be selected:



Mole Weight 97.5956

View: ● Full ○ Lumped

Options

EOS Model : Peng Robinson
Optimisation Mode : None
Separator Calc Mode : No Separators

Volume Shift
Full Composition: No Volume Shift
Lumped Composition: No Volume Shift

	Name	Mole Percent	Critical Temp.	Critical Pressure	Critical Volume	Acentric Factor	Molecular Weight	Specific Gravity	Boiling Point	Volume Shift	Omega A	Omega B	Parachor	Costald Volume
		percent	deg F	psig	ft3/lb.mole				deg F					ft3/lb.mole
1	N2	0.990001	-233.104	477.326	1.43842	0.039	28.01	1.026	-320.35	0	0.457236	0.0777961	60.4	1.44402
2	CO2	3.29	87.692	1058.26	1.50409	0.239	44.01	1.101	-109.21	0	0.457236	0.0777961	78	1.50297
3	C1	31.99	-116.518	658.381	1.58899	0.011	16.04	0.415	-258.79	0	0.457236	0.0777961	70	1.59203
4	C2	9.20001	89.798	693.651	2.37547	0.099	30.1	0.546	-127.39	0	0.457236	0.0777961	115	2.33463
5	C3	12.15	206.006	602.683	3.25166	0.153	44.1	0.585	-43.69	0	0.457236	0.0777961	155	3.20488
6	NC4	6.49001	305.294	535.963	4.08459	0.199	58.1	0.6	31.19	0	0.457236	0.0777961	200	4.07482
7	NC5	3.68	385.592	474.828	4.86948	0.251	72.2	0.63	96.89	0	0.457236	0.0777961	245	4.98673
8	C6	2.65	454.1	425.008	5.92667	0.299	86.2	0.664	155.75	0	0.457236	0.0777961	282.5	5.89783
9	C7::10	8.18855	538.658	422.016	7.44027	0.296005	117.052	0.733352	211.653	0	0.457236	0.0777961	357.808	7.88143
10	C11::14	5.9672	660.754	350.078	9.63367	0.382948	168.978	0.779301	322.608	0	0.457236	0.0777961	483.352	11.1935
11	C15::19	5.23699	876.136	240.097	15.2388	0.58686	235.709	0.842613	541.215	0	0.457236	0.0777961	621.341	15.037
12	C20::C55	10.1672	1118.61	150.605	24.3874	0.904957	411.988	0.902023	816.764	0	0.457236	0.0777961	964.116	25.0054
13														
14														
15														
16														
17														
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19														
20														
21														
22														
23														
24														
25														

2.4 The Material Balance Tool

Quotation by Muskat, taken from the 'Reservoir Engineering News Letter', September 1974:

“The Material Balance method is by no means a universal tool for estimating reserves. In some cases it is excellent. In others it may be grossly misleading. It is always instructive to try it, if only to find out that it does not work, and why. It should be a part of the 'stock in trade' of all reservoir engineers. It will boomerang if applied blindly as a mystic hocus-pocus to evade the admission of ignorance. The algebraic symbolism may impress the 'old timer' and help convince a Corporation Commission, but it will not fool the reservoir. Reservoirs pay little heed to either wishful thinking or libellous misinterpretation. Reservoirs always do what they 'ought' to do. They continually unfold a past with an inevitability that defies all 'man-made' laws. To predict this past while it is still the future is the business of the reservoir engineer. But whether the engineer is clever or stupid, honest or dishonest, right or wrong, the reservoir is always 'right'.”

Overview:

The material balance is based on the principle of the conservation of mass:

Mass of fluids originally in place = Fluids produced + Remaining fluids in place.

The material balance program uses a conceptual model of the reservoir to predict the reservoir behaviour based on the effects of reservoir fluids production and gas to water injection.

The material balance equation is zero-dimensional, meaning that it is based on a tank model and does not take into account the geometry of the reservoir, the drainage areas, the position and orientation of the wells, etc.

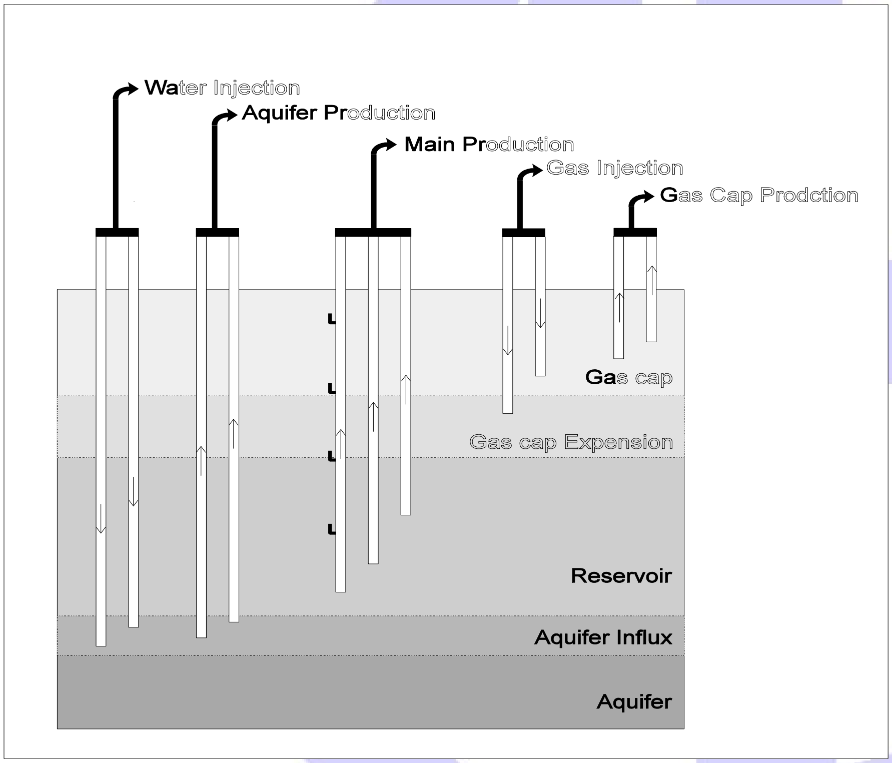
However, the material balance approach can be a very useful tool in performing many tasks, some of which are highlighted below:

- Quantify different parameters of a reservoir such as hydrocarbon in place, gas cap size, etc.
- Determine the presence, the type and size of an aquifer, encroachment angle, etc.
- Estimate the depth of the gas/oil, water/oil, gas/water contacts.
- Predict the reservoir pressure for a given production and/or injection schedule,
- Predict the reservoir performance and manifold back pressures for a given production schedule.
- Predict the reservoir performance and well production for a given manifold pressure schedule.

2.4.1 Material Balance Tank Model

Assumptions:

The material balance calculations are based on a tank model as pictured below:


Water Injection
Aquifer Production
Main Production
Gas Injection
Gas Cap Prodction
Gas cap
Gas cap Expension
Reservoir
Aquifer Influx
Aquifer

Throughout the reservoir the following assumptions apply:

- Homogeneous pore volume, gas cap and aquifers,
- Constant temperature,
- Uniform pressure distribution,

- Uniform hydrocarbon saturation distribution,
- Gas injection in the gas cap,

The Material Balance program can handle:

- Oil, gas or condensate reservoirs,
- Linear, radial and bottom drive reservoir and aquifer systems,
- Naturally flowing, gas lifted, ESP, gas or water injector wells,
- In predictive mode, automatic shut-in of well based on production or injection constraints,
- The use of tubing performance curves to predict well production,
- The use of relative permeability tables or curves.
- Multiple tanks with transmissibilities between them.
- Oil tanks with variable PVT vs. Depth.

The Material Balance tool is divided into three main sections:

Input section	where the following information can be entered: • Known and estimated reservoir parameters, • Known or estimated aquifer type and properties, • Pore volume fraction versus depth (optional), • Relative permeability curves, • Transmissibility parameters (optional), • Production and injection history on a well to well basis or total tank production.
History Matching section	where: • A graphical method (P/Z, Havlena Odeh ...) is used to quantify the missing reservoir and aquifer properties. • An iterative non linear regression is used to automatically find the best mathematical fit for a given model. • A simulation of production can be run to check the validity of the results of the above two techniques. • Gas, oil and water relative permeabilities can be estimated from historical GOR, WC or WGR
Production Prediction section	where reservoir performances can be simulated assuming: • Production and constraint schedules, • Gas contracts, • Relative permeabilities, • Well performance definitions, • A well schedule or drilling program

Note:

- It is not necessary to enter the reservoir production history to run a 'Production Prediction'.

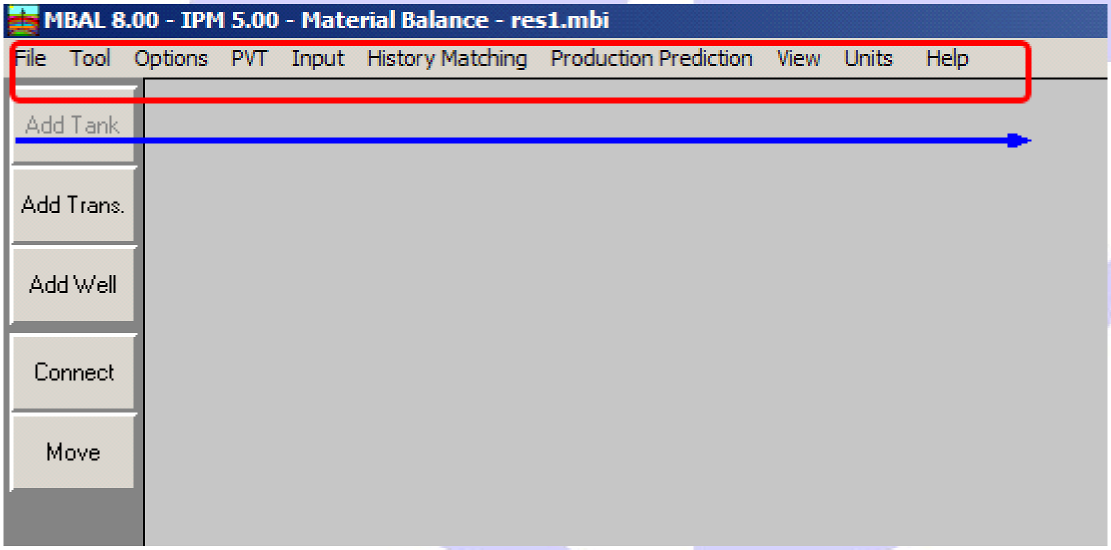
- It is highly recommended to tune the reservoir & aquifer models if any production history data is available.
- If data is unavailable upon which to match the models, the 'Production History' section of the **Input** menu, and **History Matching** menu can be left blank.
- Relative permeability curves are used for tanks, transmissibilities and wells in prediction – however their use in history matching is limited for calculation of transmissibility rates.

2.4.1.1 Recommended Workflow

The following steps should be followed in a material balance study. For more details, please refer to the tutorials in 'Appendix A' or the 'Quick Start' guide for MBAL.

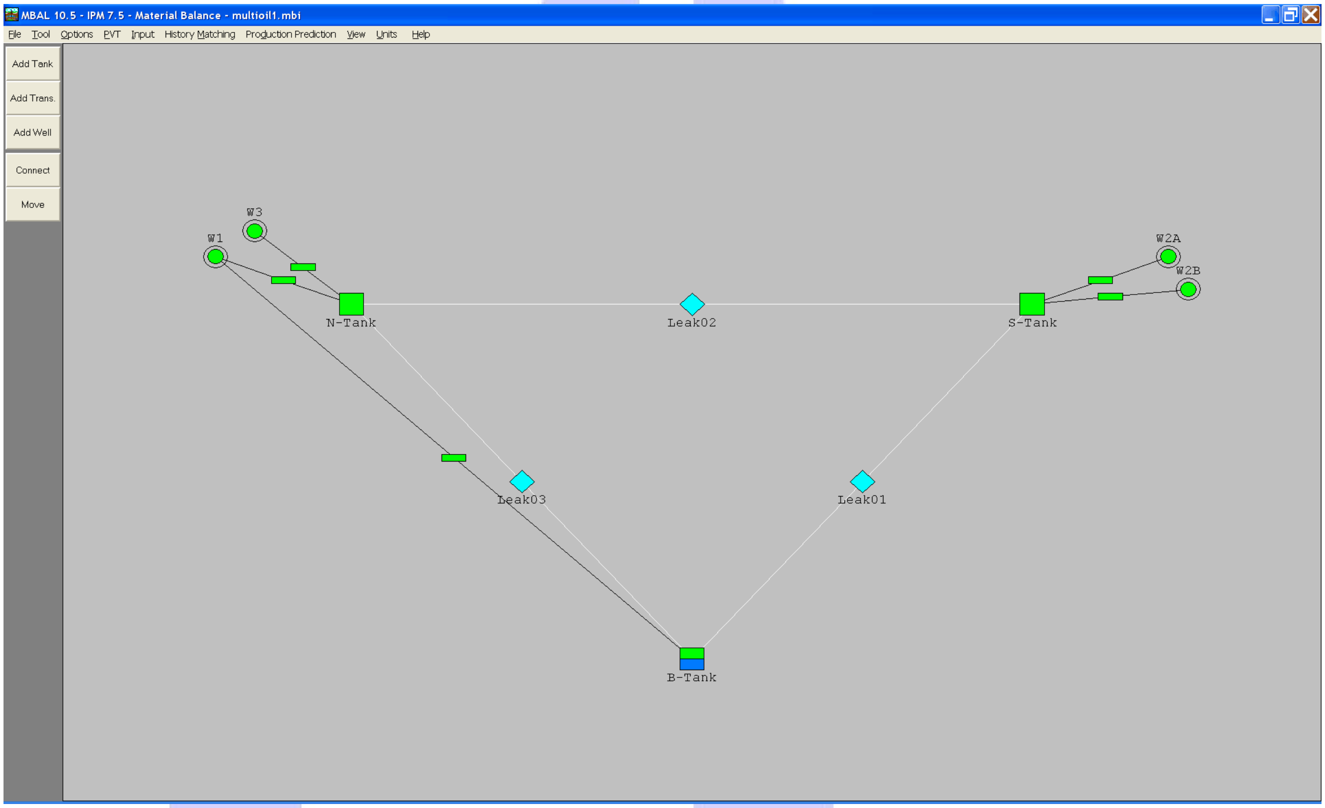
1. Make certain that the following data is available:
    - PVT,
    - Production history,
    - Reservoir average pressure history, and
    - All available reservoir and aquifer data.
2. Enter the data. At every step check the validity and consistency of the data (PVT, Pressure History, Production, etc.) ***This is the most important step in building a good model***
3. If the production history is to be entered well by well, ensure that all of the wells belong to the same tank.
4. Find the best possible match using the programs non-linear regression using the 'Analytical Method'.
5. Confirm the quality and correctness of the match, using the 'Graphical Method'.
6. Run a simulation to test the validity of the match.
7. Then and only then, go to 'Production Prediction'.

The best way to use the program is from left to right on the options menu and for each option, top to bottom as shown in the Figure below.


MBAL 8.00 - IPM 5.00 - Material Balance - res1.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Add Tank
Add Trans.
Add Well
Connect
Move

2.4.2 MBAL Graphical Interface

MBAL uses a graphical interface to facilitate the modelling of the reservoir system. All of the reservoir components such as tanks, wells and transmissibilities (communication between tanks) are represented by unique graphical objects which are easily manipulated on the screen. As components are added, the relevant input screens and fields are displayed prompting the screens in which the appropriate data is required.


MBAL 10.5 - IPM 7.5 - Material Balance - multioil1.mbi
File Tool Options PVT Input History Matching Production Prediction View Units Help
Add Tank
Add Trans.
Add Well
Connect
Move
W3
W1
N-Tank
Leak02
S-Tank
W2A
W2B
Leak03
Leak01
B-Tank

When an existing file is opened, the program will place the reservoir components in the same position as when the file was last saved. This sketch may be altered to suit personal preferences. The following sections provide an explanation on adding, moving and deleting a graphical object.

Older MBAL files can always be opened in the most recent commercial version, however, the same is not true. If a file was saved in a newer version than the one in which it is to be opened, an error message will be produced.

2.4.2.1 Manipulating Objects

The objects that can be added in the graphical plot include:

Tanks	reservoirs/layers
History Wells	these are wells that include production data which can then be allocated to tanks on a fractional basis
Prediction Wells	these are wells that can be used for forecasting (calculate rates using VLPs and IPRs for example)
Transmissibilities	used to model the interface between tanks
IPRs	used to model the interface between a tank and a prediction well (inflow performance)

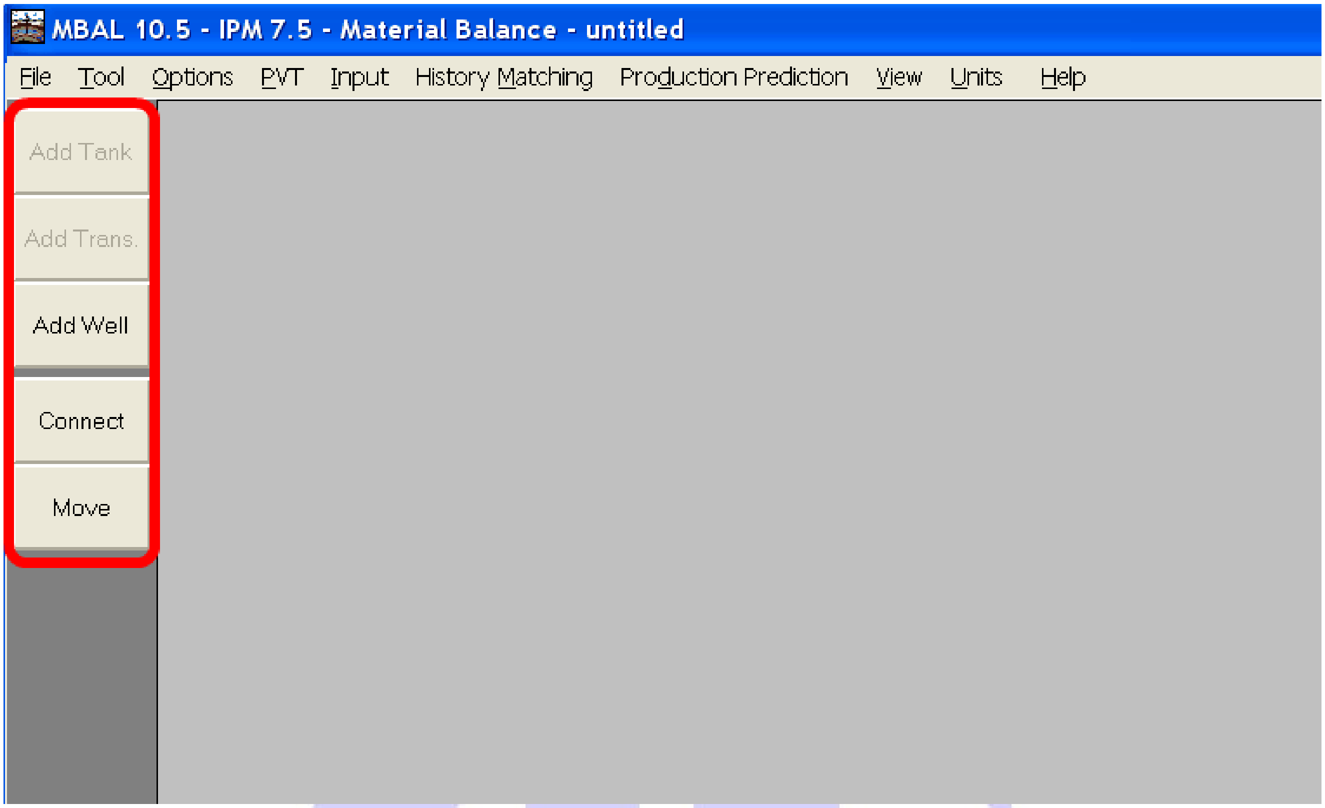
Description of the options available

Adding Objects	When opening a new data set or adding a component to an existing data set, the component must first be created. To add a new component using the icon bar: Click the appropriate component button to the left of the main screen. (e.g. **Add Tank**.) The cursor should change to the shape of the object on top of a cross-hair. Next, place the cursor anywhere on the screen and click again. Each component object has a different shape. **MBAL** currently uses simple squares to represent tanks, diamonds to represent transmissibilities, and circles to represent the wells. The data input screen for the selected component will appear. Enter the appropriate information and click **Done**. If **Cancel** is selected **MBAL** will discard the new object. ➡ Clicking on the well button will add a history well if the production history by well option is selected in the options dialogue. If production history by tank option is selected then the well button will create a history well. If in doubt, use the menu option as described below. To add a new component using the menu: Select **InputXXX Data** (For e.g.: Tank Data). The relevant input data parameter screen will appear. Click the ⊞ button to the right of the component name. When creating a new object, **MBAL** automatically provides a default name for the component selected (E.g.: Tank01). The data input screen for the new component will appear. Enter the appropriate information and click **Done**. If **Cancel** is selected by mistake, **MBAL** will discard the new object.

	To add a new component which is a copy of an existing component using the menu: Select **InputXXX Data** (For e.g.: Tank Data). The relevant input data parameter screen will appear. Select the component that is to be copied. Click the ☒ button to the right of the component name. When creating a new object, **MBAL** automatically provides a default name for the component selected based on the existing component (E.g.: Tank01-a). The data input screen for the selected component will appear with a copy of the original component. Edit any parameters which are to be altered from the original component and click **Done**. If **Cancel** is selected by mistake, **MBAL** will discard the new object.
Deleting Objects	To delete a component, double-click the appropriate component object. **MBAL** displays the data input parameter screen for the selected object. Click the ⊟ button to the right of the component name. ➡ View the input data carefully and double-check the object to be deleted. Deleted components cannot be reinstated. If a given component is not to be included in later calculations, disable the component instead. See Viewing Objects for more information. Alternatively use the pop-up Menu. Refer to Graphical Interface Pop-up Menu for more information **New in IPM 8.0*: Delete Multiple Objects*** First you need to select objects. To do this click the select button on the left hand side. Then either click each object in turn (it should then have a blue circle round it) or drag a box around all the objects you wish to select. Then to delete or disable/enable the selected objects, right click on the plot (but not on an object itself) and select from pop up menu.
Moving Objects	Once component objects have been created, manipulating their position on the screen is very easy. To move an object, press the **Shift** key and click on the object to move. Holding down the **Shift** key drag the object to its new position on the screen. Alternatively, click on the 'Move' button. The cursor should change to a shape with four arrows directed to the points of a compass. Place the cursor over the object to move, click the left mouse button and drag the object to a new position (keeping the left mouse button down). Release the left mouse button when it is moved to the new position **New in IPM 8.0*: Move Multiple Objects*** First you need to select objects. To do this click the select button on the left hand side. Then either click each object in turn (it should then have a blue circle round it)

	To move the selected objects, click the 'Move' button on the left hand side. Then click and drag (but not on a particular object alone) and all selected objects will move together.
Connecting / Disconnecting Component Objects	Connecting the appropriate components together is simple and straightforward. To connect components together, press the **Ctrl** key and click on the first object to connect. Holding down the **Ctrl** key and mouse button draw a line between connecting objects. Alternatively, click on the Connect button. Move the cursor over the first object to connect and click the left mouse button down. Holding the left mouse button down, drag the cursor to the second object and release the mouse button. If the user attempts to connect two inappropriate components, **MBAL** will not draw a line. If two tanks are connected, **MBAL** will automatically create a transmissibility object between the two tanks. If a prediction well is connected to a tank, **MBAL** will automatically create an IPR object between the prediction well and the tank
Enabling / Disabling Objects	Disabling or switching off objects is useful for excluding an object from further calculations or predictions. To disable an object simply check the ‘Disable’ option to the right of the object field name in the relevant 'Input Parameters' window. Alternatively, display the object popup menu by placing the cursor over the object to enable/disable and click the right cursor button. From the popup menu, select disable/enable. All similar objects in the data set appear by name in a column to the right of the input window. Disabled objects appear as dimmed entries and are indicated by an ‘X’ in the Input Parameters window and **MBAL** display window. To enable an object, de-select the ‘Disable’ option. Enabled objects are indicated by a check mark in the Input Parameters window. When are objects Hidden or Disabled?
Editing Objects	Double clicking on an object will display its data input dialogue. Alternatively, the input dialogue can be displayed by selecting the appropriate menu option

When the 'Material Balance' tool is selected the editing options are available from a toolbar on the right hand side of the screen:


MBAL 10.5 - IPM 7.5 - Material Balance - untitled
File Tool Options PVT Input History Matching Production Prediction View Units Help
Add Tank
Add Trans.
Add Well
Connect
Move

If the options are set up to allow multiple tanks and/or history wells, these can be added to the system by using the component buttons highlighted above.

To add a new component in the model:

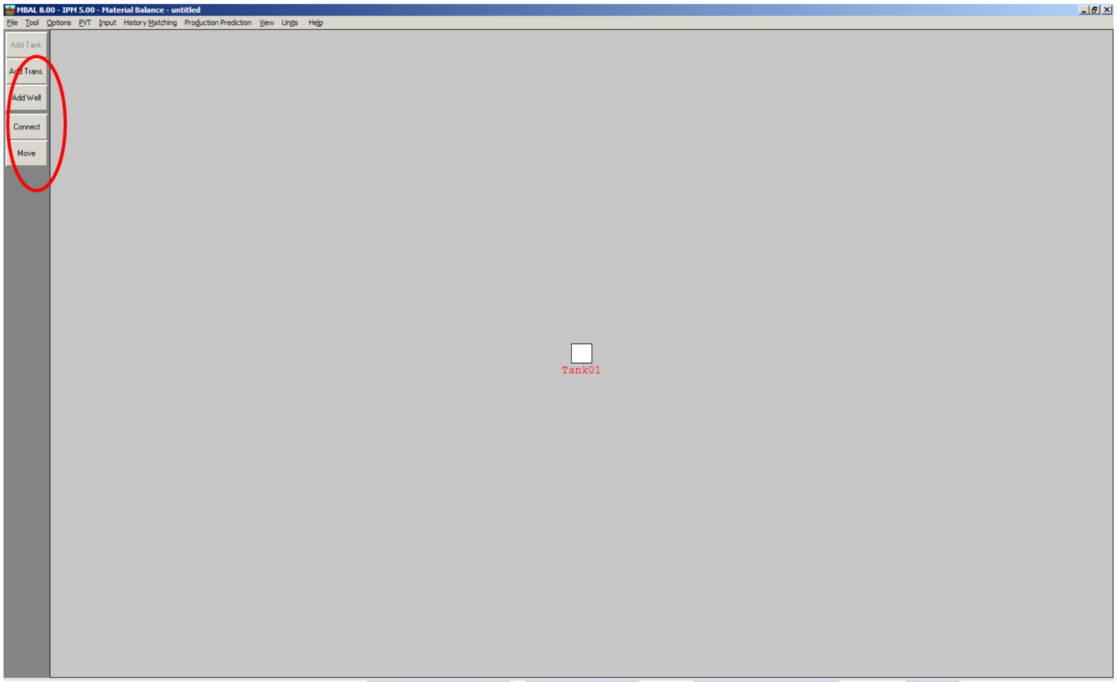
- Click the appropriate component button to the left of the main screen. (E.g.: Add Tank). The cursor should change to the shape of the object on top of a cross-hair. Next, place the cursor anywhere on the screen and click again. Each component object has a different shape. **MBAL** currently uses squares to represent tanks, diamonds to represent transmissibilities, and circles to represent the wells. The data input screen for the selected component will appear. Enter the appropriate information and click **Done**. If **Cancel** is selected, **MBAL** will discard the new object.

➡ **These options will be explored further in the form of examples later on. Refer to the Multi-Tank example in Appendix A for instance. This illustrates how more than one reservoirs or wells are added to the system, based on the requirements for modelling a situation**

Moving Objects

To move an object, press the **Shift** key and click on the object to move. Holding down the **Shift** key and dragging the object, will place it on a different position on the screen.

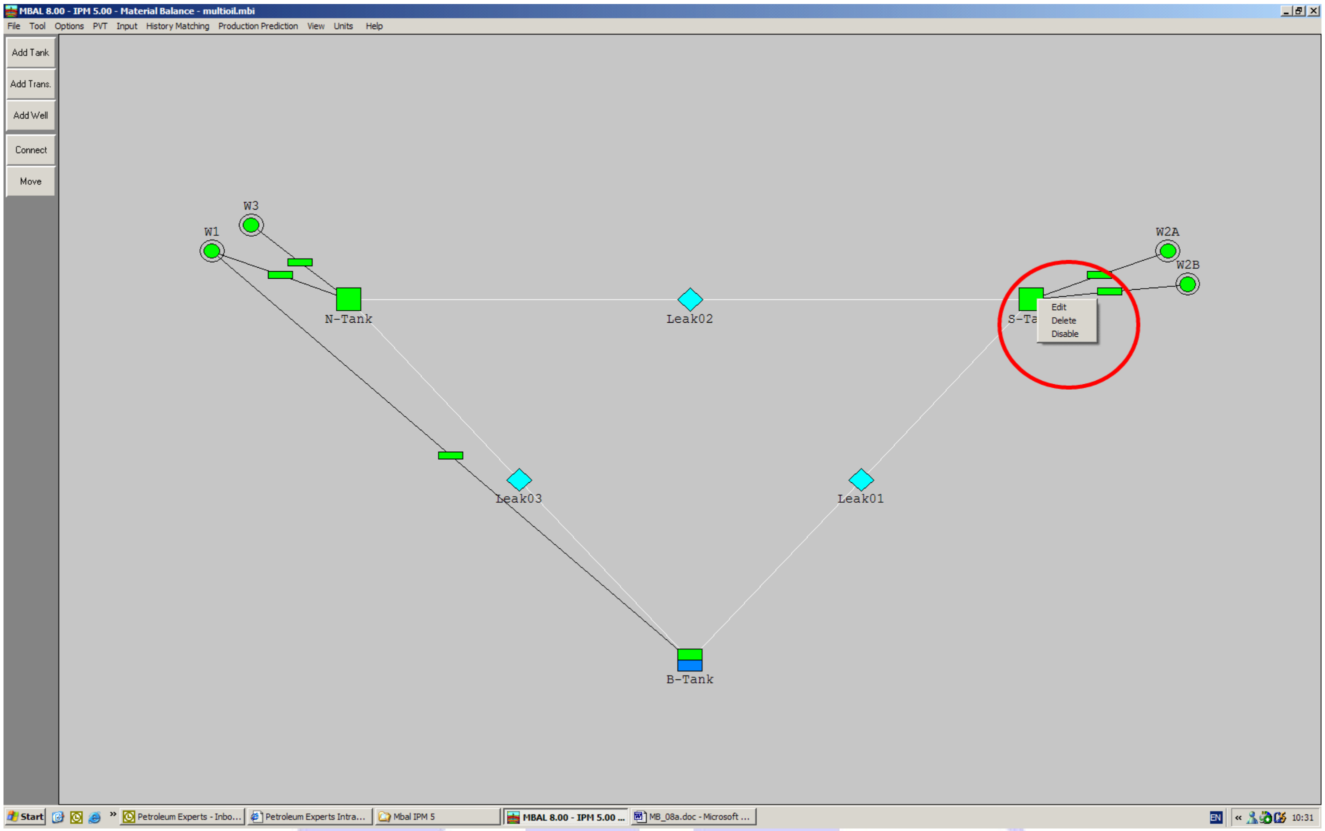
Alternatively, click on the 'Move' button as shown below:


MBAL 8.00 - IPM 5.00 - Material Balance - untitled
File Tool Options PVT Input History Matching Production Prediction View Units Help
Add Tank
Add Trans.
Add Well
Connect
Move
Tank01

The cursor will change to a shape with four arrows directed to the points of a compass. Place the cursor over the object to move, click the left mouse button and drag the object to a new position (keeping the left mouse button down). Release mouse button when the object is moved to the new position.

Enabling / Disabling Objects

Objects can be very simply disabled from the screen by right-clicking on an object. This will prompt a menu on which the 'Disable' option can be selected:


MBAL 8.00 - IPM 5.00 - Material Balance - multioil.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Add Tank
Add Trans.
Add Well
Connect
Move
W3
W1
N-Tank
Leak02
S-Ta
Edit
Delete
Disable
W2A
W2B
Leak03
Leak01
B-Tank
Start
Petroleum Experts - Inbo...
Petroleum Experts Intra...
Mbal IPM 5
MBAL 8.00 - IPM 5.00 ...
MB_08a.doc - Microsoft ...
EN
10:31

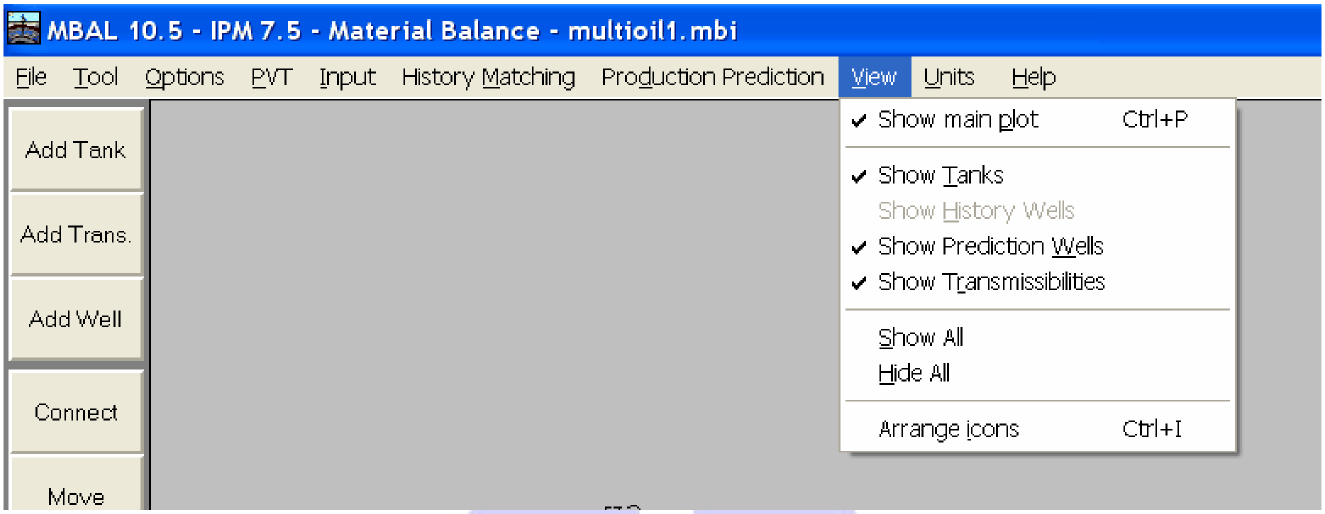
This object will now be greyed-out from the screen and will be excluded from further calculations.

The same pop-up menu can also be used to delete or Edit items by selecting the relevant option.

Make sure that everything is written in third person, no 'you'.

2.4.2.2 Viewing Objects

In a situation where a large number of components and data are present and need to be manipulated; **MBAL** has a facility allowing efficient viewing and handling of the data. These editing facilities are located under the **View** menu.


MBAL 10.5 - IPM 7.5 - Material Balance - multioil1.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Add Tank
Add Trans.
Add Well
Connect
Move
✓ Show main plot Ctrl+P
✓ Show Tanks
Show History Wells
✓ Show Prediction Wells
✓ Show Transmissibilities
Show All
Hide All
Arrange icons Ctrl+I

Options available

Show Main Plot	Use this option to clear the graphical display screen. All objects and connections are erased from the screen but not deleted. Use this option if it is desired to switch off the graphical interface or remove the sketch from the screen. A check indicates the option is 'On'
Show Tanks	Use this menu option to display all the tank components in the data set. A check indicates the option is 'On'. Turning the option 'Off' hides all the tanks in the current data set. By turning 'Off' the other components in the data set, this facility can be used to confine the display to the objects to be viewed or edited
Show Wells	Use this menu option to display all the well components in the data set. A check indicates the option is 'On'. Turning the option 'Off' hides all the wells in the current data set. By turning 'Off' the other components in the data set, this facility can be used to confine the display to the required objects
Show Transmissibilities	Use this menu option to display all the transmissibilities components in the data set. A check indicates the option is 'On'. Turning the option 'Off' hides all the transmissibilities in the current data set. By turning 'Off' the other components in the data set, this facility can be used to confine the display to the desired objects
Show All	This menu option displays all objects. Use this option to display all hidden components
Hide All	This menu option hides all objects. Hidden objects are included in the calculations if they are enabled
Arrange Icons	Use this menu option to rearrange the graphical display. Objects are arranged in a more orderly manner to facilitate editing and viewing. Use this option to redraw the sketch model after deleting objects from the data set. When updating older data sets to the new version, use this option to

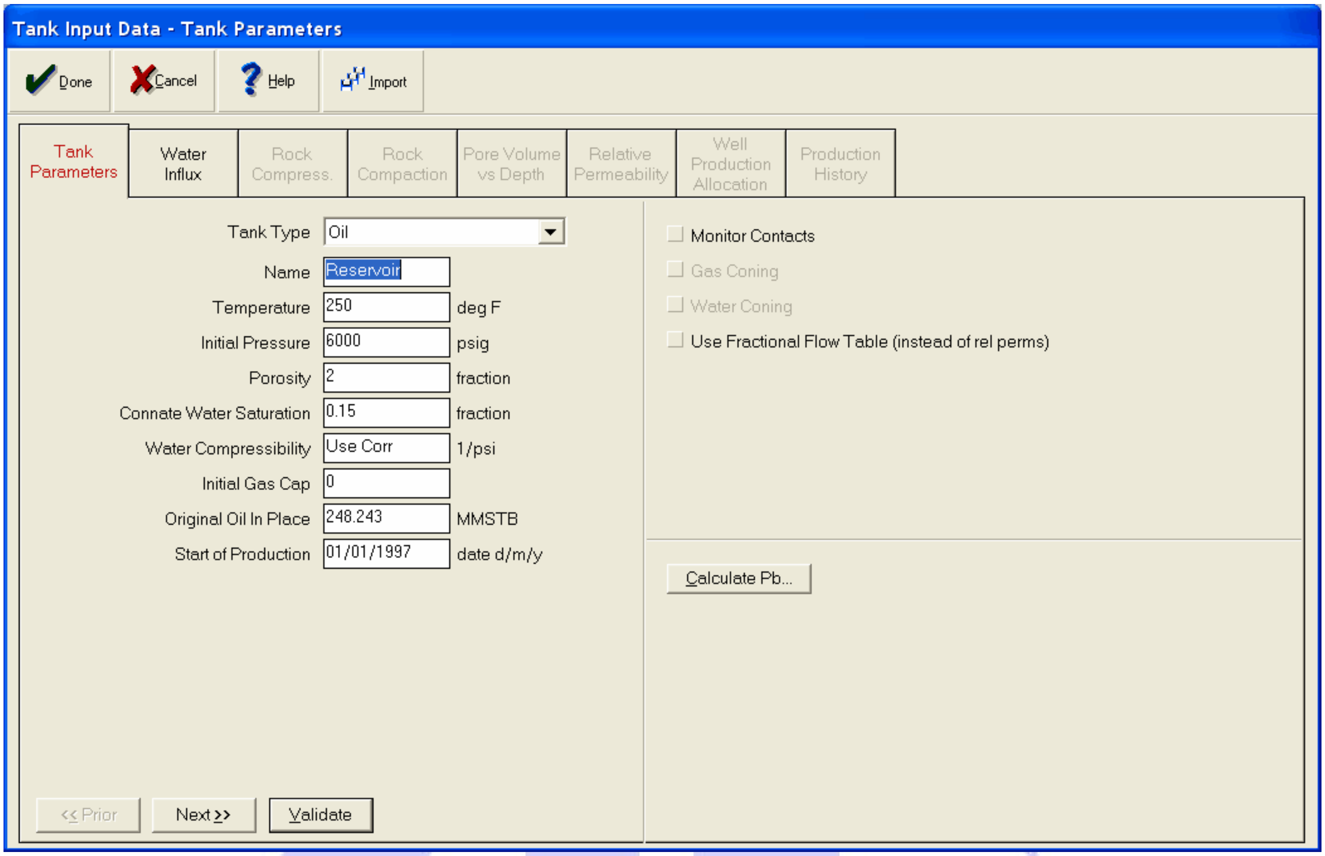
	draw a sketch of the existing components in the data set
Arrange Icons	Use this menu option to rearrange the graphical display. Objects are arranged in a more orderly manner to facilitate editing and viewing. Use this option to redraw the sketch model after deleting objects from the data set. When updating older data sets to the new version, use this option to draw a sketch of the existing components in the data set
Colour code Transmissibilities & Size code Transmissibilities	***New in IPM8.0*** This essentially is a graphical manipulation of the transmissibilities (e.g. size and colour)

For a more information on hidden and enabled objects, see Hidden or Disabled Objects.

2.4.2.3 Validating Object Data

The MBAL smart data validation system allows the user to move freely within the input section of the program, even if the data entered is invalid. As long as input data remain invalid, no calculations can be carried out.

If data entered in any particular screen is invalid, then the title of this screen will appear in red:


Tank Input Data - Tank Parameters
Done
Cancel
Help
Import
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Well Production Allocation
Production History
Calculate Pb...
<< Prior
Next >>
Validate

Tank Type: Oil

Name: Reservoir

Temperature: 250 deg F

Initial Pressure: 6000 psig

Porosity: 2 fraction

Connate Water Saturation: 0.15 fraction

Water Compressibility: Use Corr 1/psi

Initial Gas Cap: 0

Original Oil In Place: 248.243 MMSTB

Start of Production: 01/01/1997 date d/m/y

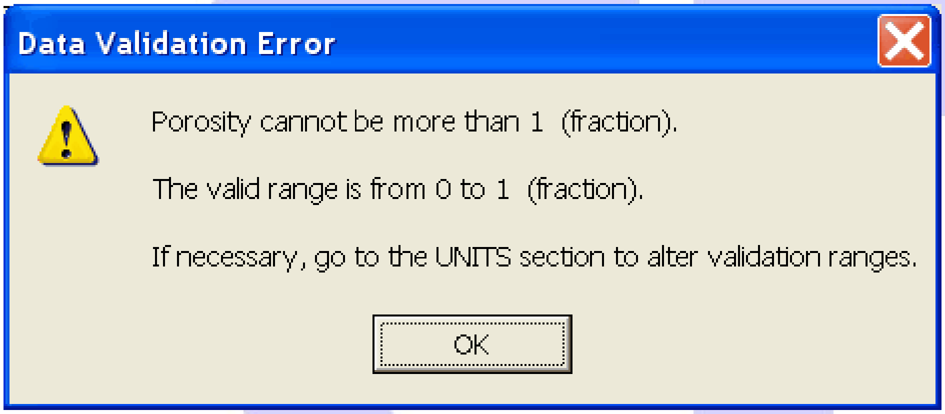
☐ Monitor Contacts

☐ Gas Coning

☐ Water Coning

☐ Use Fractional Flow Table (instead of rel perms)

If the 'Validate' button is selected, then a message with the cause of the validation error will appear:


Data Validation Error
OK

Porosity cannot be more than 1 (fraction).

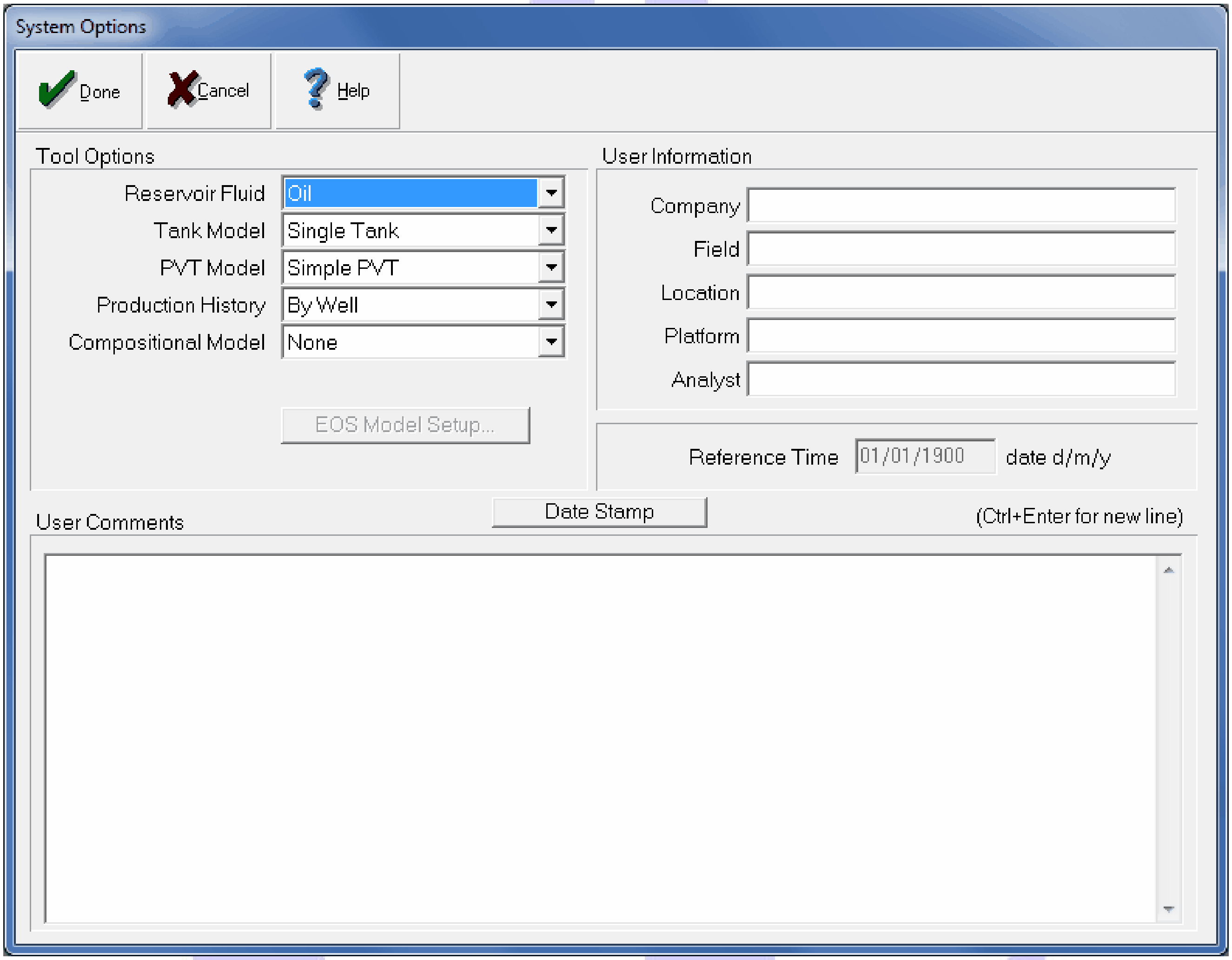
The valid range is from 0 to 1 (fraction).

If necessary, go to the UNITS section to alter validation ranges.

➡ **Data sheet titles highlighted in MAGENTA are empty but not invalid - this is only a warning**

2.4.3 Tool Options

Having selected 'Material Balance' from the 'Tool' menu, the 'Options' menu can be opened to define the system setup. This section describes the 'Tool Options' section of the system options dialogue box.


System Options
Done
Cancel
Help
Tool Options
User Information
EOS Model Setup...
User Comments
Date Stamp
(Ctrl+Enter for new line)

Reservoir Fluid: Oil
Tank Model: Single Tank
PVT Model: Simple PVT
Production History: By Well
Compositional Model: None

Company:
Field:
Location:
Platform:
Analyst:

Reference Time: 01/01/1900 date d/m/y

To select an option, click the arrow to the right of the field to display the current choices. To move to the next entry field, click the field to highlight the entry, or use the **TAB** button.

Input Fields

Reservoir Fluid	Choose from: **Oil** — This option models oil reservoirs

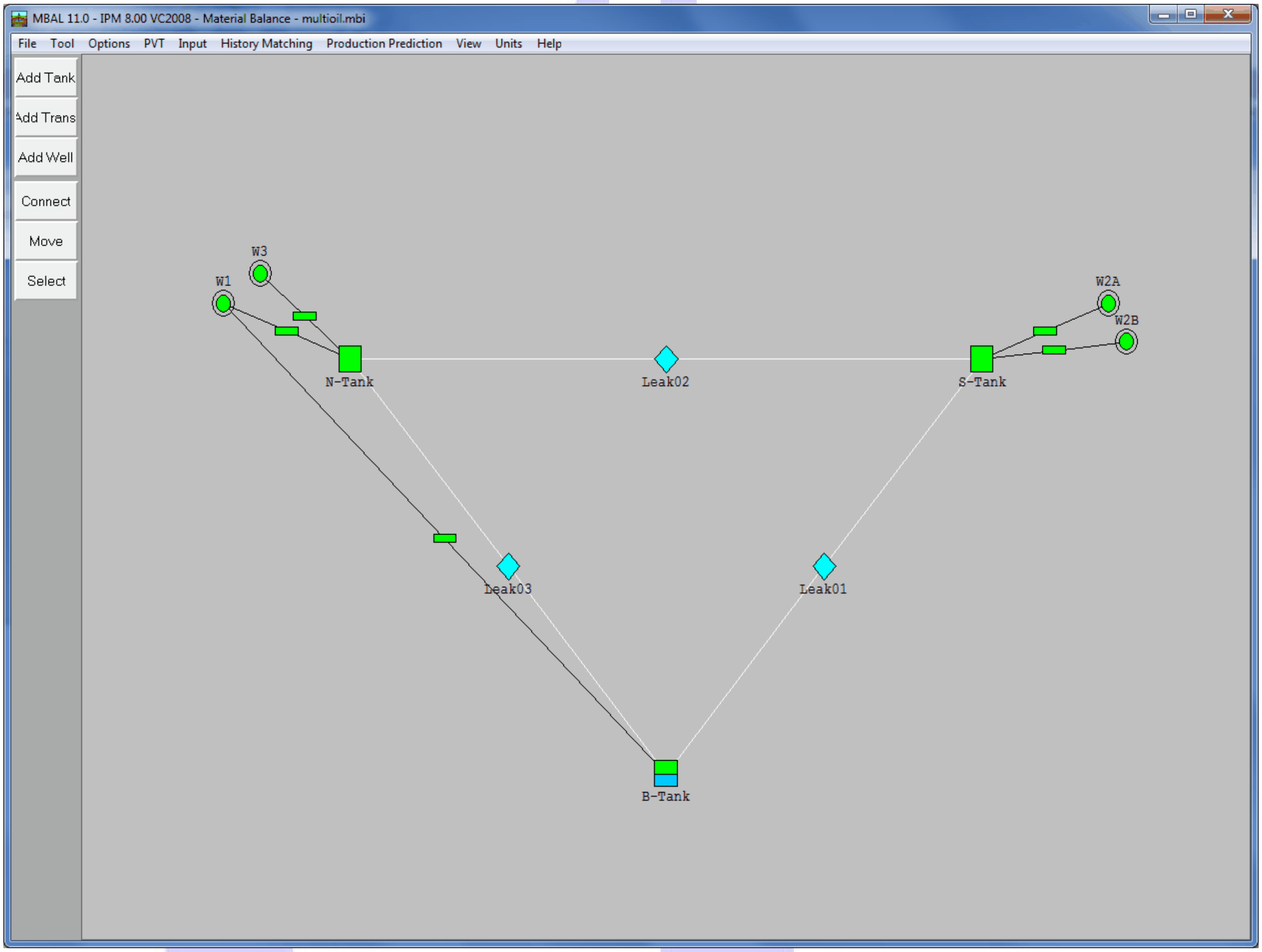
<table>
<tr><td></td><td>
<table>
<tr><td>Gas</td><td>(Dry and Wet Gas)
Wet gas is handled under the assumption that condensation occurs at the separator. The liquid is put back into the gas as an equivalent gas quantity. The pressure drop is therefore calculated on the basis of a single phase gas, unless water is present</td></tr>
<tr><td>Retrograde Condensate</td><td>The program uses the retrograde condensate black oil model. These models take into account liquid dropout at different pressure and temperatures</td></tr>
<tr><td>General</td><td>The program uses a general fluid model. See Generalised Material Balance for more information</td></tr>
</table>
For further information relating to the modelling of reservoir fluids in MBAL, see Describing the PVT 70.
</td></tr>
<tr><td>Tank Model</td><td>Two options are available:
<table>
<tr><td>Simple</td><td>In this mode MBAL will run a single tank reservoir model. If this model is selected when more than one tank exists, the currently selected tank will be modelled</td></tr>
<tr><td>Multiple Tank</td><td>In this mode a multiple tank reservoir model with potentially different PVT per tank can be defined</td></tr>
</table>
</td></tr>
<tr><td>PVT Model</td><td>(only available if reservoir fluid is set to 'Oil' or 'General')
<table>
<tr><td>Simple</td><td>In this mode, the program uses a single PVT model, that is to say, the PVT properties are the same everywhere in the tank</td></tr>
<tr><td>Variable PVT</td><td>In this mode, MBAL uses a number of PVT models specified over different depths in the reservoir. See Material Balance with Variable PVT for more information</td></tr>
</table>
For further details, see Describing the PVT 70
</td></tr>
<tr><td>Abnormally Pressured</td><td>(only available if reservoir fluid is set to gas)
Two options are available:
<table>
<tr><td>No</td><td>Normal method using fixed, correlated or table of rock compressibilities</td></tr>
<tr><td>Yes</td><td>Select this method if the 'Abnormally Pressured Method' is to be employed when modelling the rock compaction</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><td></td><td>This model is as described in A Semianalytical p/z Technique for the Analysis of Reservoir Performance from Abnormally Pressured Gas Reservoirs, Ronald Gunawan Gan, SPE, Vico Indonesia, and T.A. Blasingame, SPE, Texas A&M University, SPE 71514. It is recommended that this paper is read before using this method.
To summarise this method; it is based on the pattern of two straight lines often seen in the P/Z plot for abnormally pressured reservoirs. The early straight line is due to the rock compaction. At a certain pressure the reservoir stops compacting. Below this pressure a second straight line develops which is due only to the gas expansion.
The compressibility function Ce(Pi-P) that is developed from this theory is defined by three parameters:
• OGIP Apparent
• OGIP Actual
• P/Z Inflection
The 'OGIP apparent' is the OGIP calculated from the early line on the P/Z plot. The 'OGIP actual' is the OGIP calculated from the late line on the P/Z plot. The P/Z inflection is the pressure at which the two lines intersect.
The value of the Ce(Pi-P) function increases as the pressure drops to the P/Z Inflection value. Below this pressure this Ce(Pi-P) remains at a constant value.
If this method is selected then the normal history matching plots are replaced by two plots, a P/Z Plot and a Type Curve Plot.
The P/Z plot allows two straight lines to be drawn to make a first estimate of the three input parameters.
The Type Curve Plot displays the data as Ce(Pi-P) vs (P/Z)/(P/Z)i. A number of type curves are displayed to guide the user to the best match. There is also an automatic regression calculation to find the best fit for the three input parameters.
Having defined the Ce(Pi-P) model using the history methods; the material balance calculations in the history simulation production prediction are performed exactly as before. The only difference is that the calculation of the pore volume at each pressure uses the new Ce(Pi-P) function rather than the input rock compressibility</td></tr>
<tr><td>Production History</td><td>Two options are available:
<table>
<tr><td>By Tank</td><td>This option requires the production history to be entered for each tank. The tank production history can then be used for history matching</td></tr>
<tr><td>By Well</td><td>This option should be used if the production history per well is available and the wells either take production from more than</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><td></td><td>
<table>
<tr><td></td><td>one tank or more than one well takes production from a single tank. In this case, the production history for each well and allocation factor to each tank will need to be entered – MBAL will then calculate the production history for each tank which can then be used in history matching</td></tr>
</table>
</td></tr>
<tr><td>Compositional Model</td><td>
<table>
<tr><td>None</td><td>In this mode all calculations are black oil models only</td></tr>
<tr><td>Tracking</td><td>This option is basically the same as the 'none' option. However in this mode, the history simulation and production prediction will track the composition in the tanks and calculate compositions produced by each well. This is a post-processing calculation and will not effect the tank pressure calculations. See Compositional Tracking 143 for more information</td></tr>
<tr><td>Full Calculation</td><td>In this mode, all calculations are performed using a full composition model so no black oil model is required. See 'Full Compositional Model' for more information</td></tr>
</table>
These options are listed and explained Compositional Modelling 134
</td></tr>
<tr><td>Reference Time</td><td>
The format that time data is displayed in MBAL can be of two types:
<table>
<tr><td>Date</td><td>A calendar date displayed in the format defined by Windows e.g. 23/12/2001 or 02/28/98</td></tr>
<tr><td>Time</td><td>A decimal number of days, weeks, months or years since a reference date</td></tr>
</table>
The format is selected for the time unit type in the Units dialogue.
If days, weeks, months or years (rather than date format) have been selected, this field allows entering the reference date.
</td></tr>
<tr><td>User Information</td><td>The information for these fields is optional. The general details entered here provide the banner/header information that identify the reservoir in the reports and plots generated by the program</td></tr>
<tr><td>User Comments and Date Stamp</td><td>Space where a log of the updates or changes to the file can be stored. This comments box can also be used to exchange information between users. An unlimited amount of text is allowed.
Press Ctrl+Enter to start a new paragraph.
The comments box can be viewed by either dragging the scroll bar thumb or using the up and down directional arrow keys.
The Date Stamp command adds the current date and time to the User Comments Box</td></tr>
</table>

2.4.4 Input

The following sections describe the **MBAL** program **Input** menu.


MBAL 11.0 - IPM 8.00 VC2008 - Material Balance - multioil.mbi
File Tool Options PVT Input History Matching Production Prediction View Units Help
Add Tank
Add Trans
Add Well
Connect
Move
Select
W3
W1
W2A
W2B
N-Tank
Leak02
S-Tank
Leak03
Leak01
B-Tank

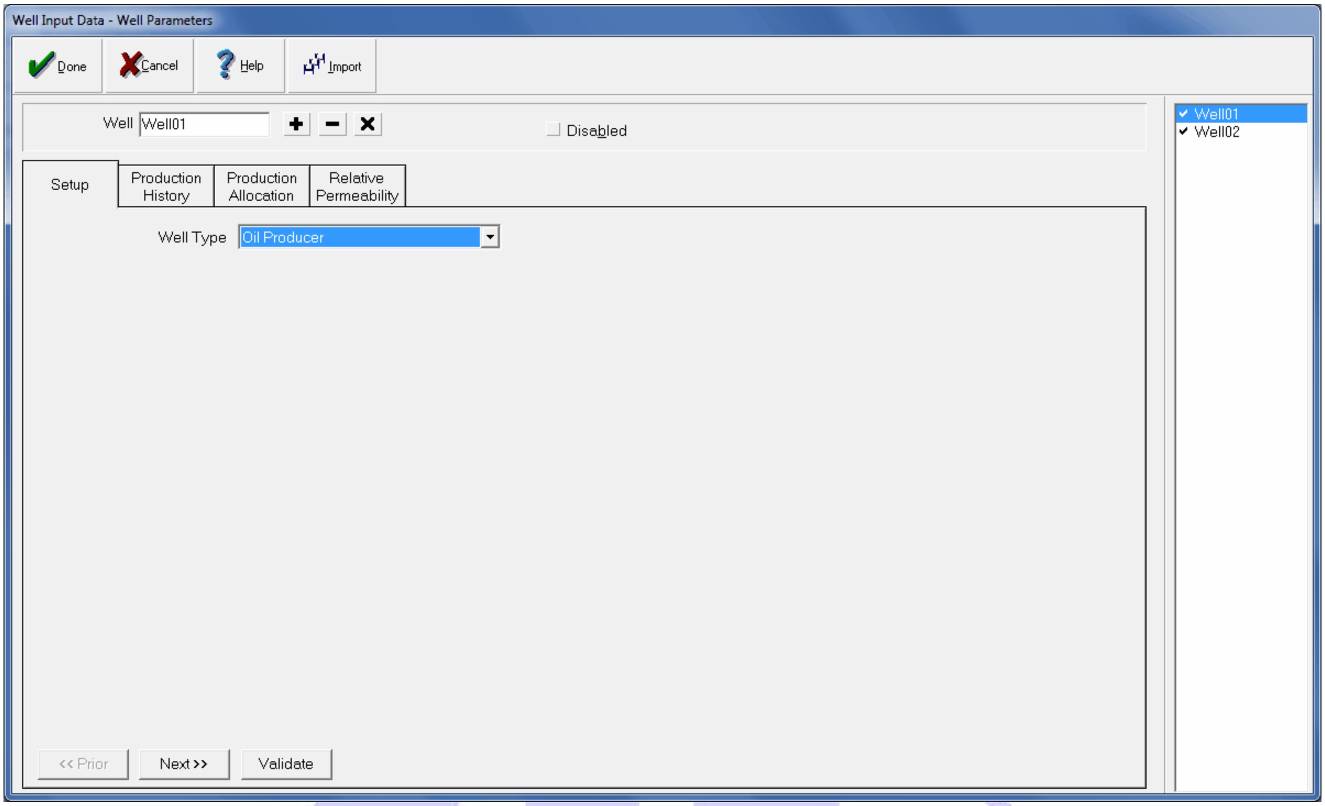
2.4.4.1 Wells Data

This option is enabled only if the “By Well” option is chosen of the Production History field in the Options menu. The 'Well Parameters' dialogue box is used to enter the pressure and the cumulative production or injection history for a well or group of wells.

2.4.4.1.1 Setup

This option is enabled only if the *by Well* option of the 'Production History' field in the **Options** Menu is selected. The **Well Setup** data page is used to setup a well or group of wells.

A screen, as seen below, will appear:


Well Input Data - Well Parameters
Done
Cancel
Help
Import
Well
+
−
×
Disabled
Well01
Well02
Setup
Production History
Production Allocation
Relative Permeability
<< Prior
Next >>
Validate

Well: Well01

☐ Disabled

Well Type: Oil Producer

A well can be created by clicking on the + button shown above. Similarly, a well can be deleted or copied by using the – or X buttons.

Input Fields

Well Type	Define the flow type of the well selected in the 'Setup' data sheet
Perforation Top	(for Variable PVT only) Defines the depth of the top of the perforation where the well perforates the tanks. Note that for the current release we assume the same perforation heights for all the tanks that intersect this well
Perforation Bottom	(for Variable PVT only) Defines the depth of the bottom of the perforation where the well perforates the tanks. Note that for the current release we assume the same perforation heights for all the tanks that intersect this well

Steps to follow:

- Select a well from the list to the right of the dialogue
- Next, select the well type from a drop down list containing a variable selection of flow types. The well type selected determines the remaining data sheets to be entered.

Data sheets containing invalid information for the well type selected will automatically be highlighted in RED.

- Press 'Validate' to run the validation procedure and pinpoint the input error. If no further data is required for the well, the data sheet(s) may be accessed.

Command Buttons

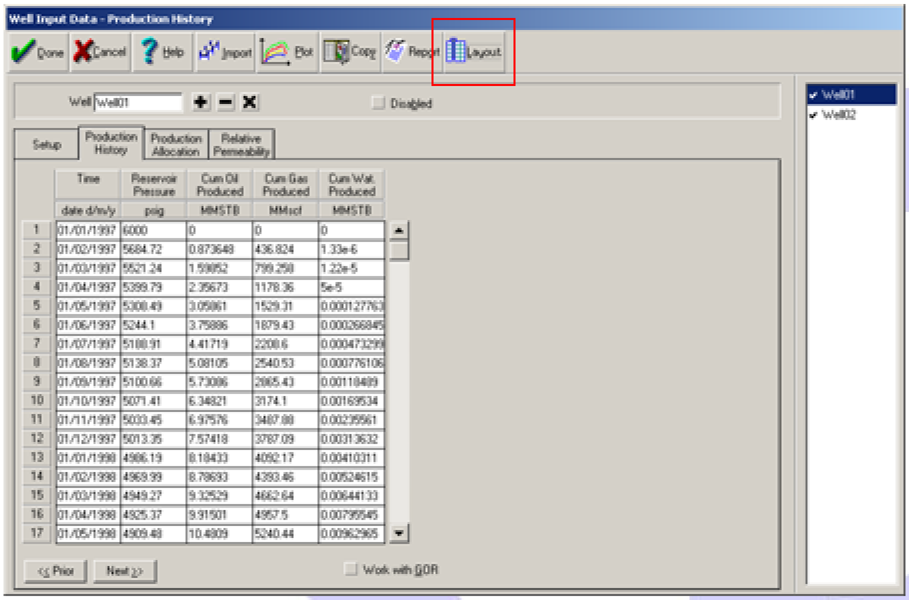
Import	This option is used to import a number of wells and their production data from a Production Analyst (*.REP) file. If some wells already exist it will simply append the wells to the end of the list. **MBAL** will ask whether to overwrite or skip a well if one in the PA file is also currently stored in **MBAL**

.

2.4.4.1.2 Production / Injection History

To access the production or injection history, choose the Input|Wells Data menu and select the 'Production History' tab. For existing wells, enter the cumulative production plus the static pressure in each wells drainage volume where available. Production data can be entered even when no pressure values are available.

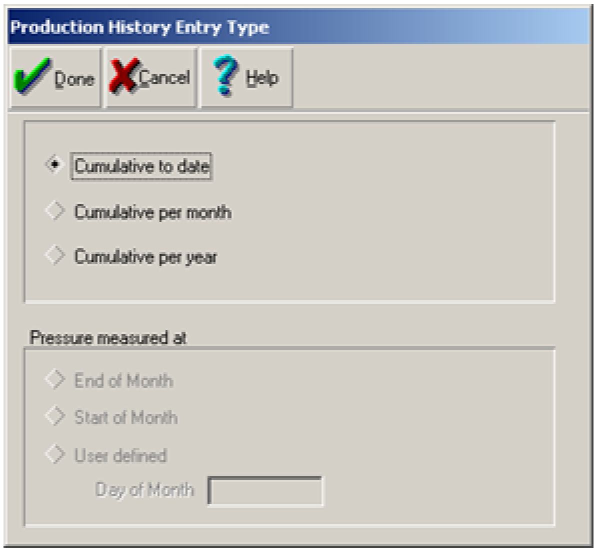
In previous versions of **IPM**, the historical fluid rates needed to be entered cumulatively. **In IPM version 7, a new option is available;**



Well Well01

	Time	Reservoir Pressure	Cum Oil Produced	Cum Gas Produced	Cum Wat. Produced
	date d/m/y	psig	MMSTB	MMscf	MMSTB
1	01/01/1997	6000	0	0	0
2	01/02/1997	5684.72	0.873648	436.824	1.33e-6
3	01/03/1997	5521.24	1.59852	799.258	1.22e-5
4	01/04/1997	5399.79	2.35673	1178.36	5e-5
5	01/05/1997	5308.49	3.05861	1529.31	0.000127763
6	01/06/1997	5244.1	3.75886	1879.43	0.000266845
7	01/07/1997	5188.91	4.41719	2208.6	0.000473299
8	01/08/1997	5138.37	5.08105	2540.53	0.000776106
9	01/09/1997	5100.66	5.73086	2865.43	0.00118489
10	01/10/1997	5071.41	6.34821	3174.1	0.00169534
11	01/11/1997	5033.45	6.97576	3487.88	0.00235561
12	01/12/1997	5013.35	7.57418	3787.09	0.00313632
13	01/01/1998	4986.19	8.18433	4092.17	0.00410311
14	01/02/1998	4969.99	8.78693	4393.46	0.00524615
15	01/03/1998	4949.27	9.32529	4662.64	0.00644133
16	01/04/1998	4925.37	9.91501	4957.5	0.00795545
17	01/05/1998	4909.48	10.4809	5240.44	0.00962965

Selecting the 'Layout' button will result in the following screen:


Production History Entry Type
Done
Cancel
Help
Pressure measured at
Day of Month

● Cumulative to date
○ Cumulative per month
○ Cumulative per year

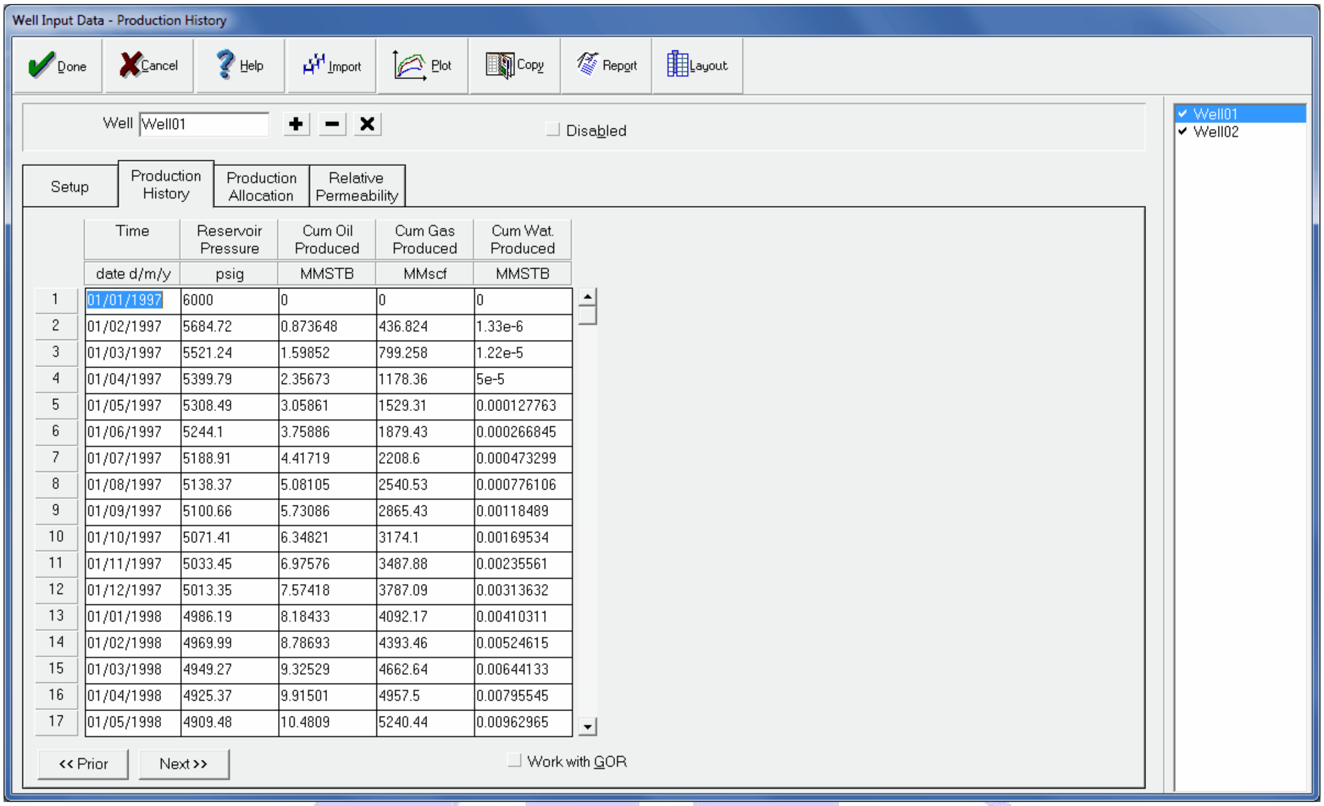
○ End of Month
○ Start of Month
○ User defined

The historical data can now be entered as a cumulative rate over a given time step, either per month or per year.

➲ **The production/injection, GOR and CGR entered must be cumulative. Note that Cumulative GOR = Cum Gas / Cum Oil.**

2.4.4.1.3 Well Production History

This option is enabled only if the *by Well* option of the Production History field in the **Options** Menu is selected. The **Well Production History** data page is used to enter the cumulative production plus the static pressure in each well's drainage volume where available.



Well: Well01

☐ Disabled

☐ Work with GOR

☑ Well01
☑ Well02

	Time	Reservoir Pressure	Cum Oil Produced	Cum Gas Produced	Cum Wat. Produced
	date d/m/y	psig	MMSTB	MMscf	MMSTB
1	01/01/1997	6000	0	0	0
2	01/02/1997	5684.72	0.873648	436.824	1.33e-6
3	01/03/1997	5521.24	1.59852	799.258	1.22e-5
4	01/04/1997	5399.79	2.35673	1178.36	5e-5
5	01/05/1997	5308.49	3.05861	1529.31	0.000127763
6	01/06/1997	5244.1	3.75886	1879.43	0.000266845
7	01/07/1997	5188.91	4.41719	2208.6	0.000473299
8	01/08/1997	5138.37	5.08105	2540.53	0.000776106
9	01/09/1997	5100.66	5.73086	2865.43	0.00118489
10	01/10/1997	5071.41	6.34821	3174.1	0.00169534
11	01/11/1997	5033.45	6.97576	3487.88	0.00235561
12	01/12/1997	5013.35	7.57418	3787.09	0.00313632
13	01/01/1998	4986.19	8.18433	4092.17	0.00410311
14	01/02/1998	4969.99	8.78693	4393.46	0.00524615
15	01/03/1998	4949.27	9.32529	4662.64	0.00644133
16	01/04/1998	4925.37	9.91501	4957.5	0.00795545
17	01/05/1998	4909.48	10.4809	5240.44	0.00962965

The data required are:

- **Time**
- **Reservoir Pressure**
- **Cumulative Oil Produced**
- **Cumulative Gas Produced**
- **Cumulative Water Produced**
- **Cumulative Gas Injected (gas injection wells)**
- **Cumulative Water Injected (water injection wells)**

Production data can be entered even when no pressures are available. The various well production tables may later be consolidated using the 'allocation factor' on each table which allows the entire, part of, or none of the production /injection history to be allocated to the tank. It will also attempt to calculate the tank pressure using the well static pressures. Production data can be entered even when no pressures are available. This is done in the Tank Production History tab. 203

➡ The production/injection GOR entered must be cumulative. Note that Cumulative GOR = Cum Gas / Cum Oil. Refer to Tank Production History 203 for more information.

See Table Data Entry for more information on entering the production history.

Procedure

- Select a well from the list to the right of the dialogue
- Enter the available production history data.
- Press 'Validate' to run the validation procedure and pinpoint any input error.
- If no further data is required for the well, the **Production Allocation** tab may be accessed. This allows the user to enter the data to determine which tanks the wells production is allocated to and how much.

Well Control Fields

See Well Control Fields for more information.

Input Fields

Work with GOR	(**Oil and Gas condensate Wells Only**) Check this box if the cumulative GOR instead of the gas cumulative production is to be entered. When the GOR is supplied, the program automatically calculates the gas cumulative production
Work with CGR	(**GAS Wells Only**) Check this box if the cumulative CGR is a preferred value to the condensate cumulative production. When the CGR is input, the program automatically calculates the condensate cumulative production

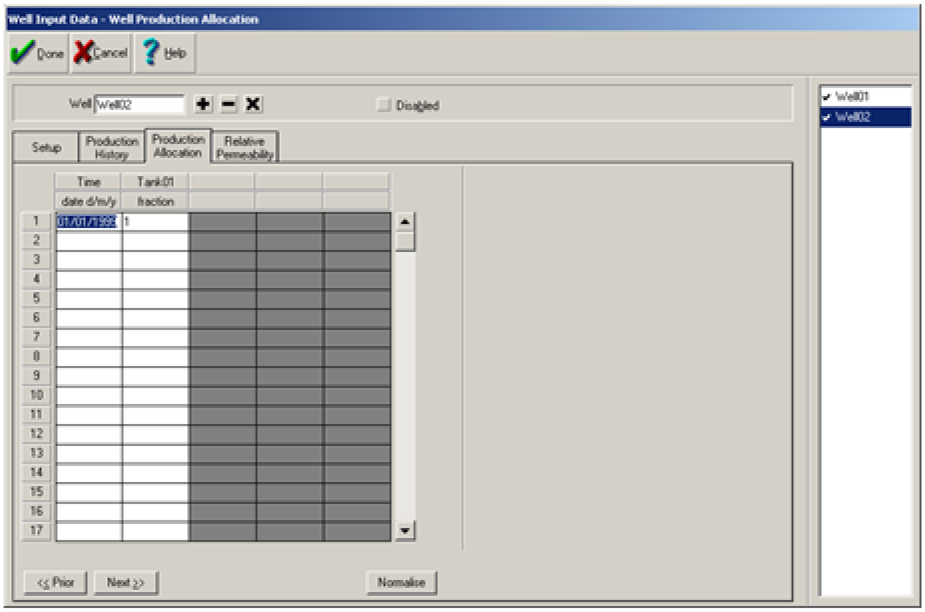
Command Buttons

Import	This option is used to import production data from an external file. Note that if any production data exists for the current well, the user will be asked if it is desired to replace the existing data or append to the existing data. This file can either be: • An ASCII file in which the user must specify a filter to define the columns in the file and how they translate to the MBal data columns. • A Petroleum Expert's *.HIS history file. • An ODBC data source. • A Production Analyst (*.REP) file. This file can contain production data for a number of tanks. MBal will search for the tank name in the file that matches the currently selected tank - if it finds one then it will import the production data for that tank
Plot	Displays the different production / injection, GOR and CGR data points versus Time. Click on 'Variable' to select another data column to plot
Report	Allows creation of reports of production history data

2.4.4.1.4 Production Allocation

This screen is used to allocate the well production to the different tanks if the well is producing from more than one reservoir (multi-layer system). This enables the program to consolidate the tank production history on which history matching will be done.

To access the production allocation, choose the Input | Wells Data menu and select the 'Production Allocation' tab. A screen, as seen below, will appear:


Well Input Data - Well Production Allocation
Done
Cancel
Help
Disabled
Setup
Production History
Production Allocation
Relative Permeability
<< Prior
Next >>
Normalise
✓ Well01
✓ Well02

Well Well02

	Time	Tank01
	date d/m/y	fraction
1	01/01/199[illegible]	1

The following steps are required:

1. First select the producing tanks:

The 'Producing From' list shows which tanks are connected to the current history well. The tanks can be connected/disconnected to the current well by selecting or deselecting the tank in the 'Producing From' list. The tank will be added to the allocation table.

2. Next allocate a production fraction to each well:

Allocation Fraction	The fraction of the well production or the injection history to be allocated to the tank. This defines the multiplying coefficient to use for this well when the well histories are consolidated. Any value between 0 and 1 is valid. 1.0 allocates the complete well production/injection to a particular reservoir. If this fraction changes over time, enter more than one row in the table. Each row should define the time at which the allocation factor takes effect. (See 'Reservoir Production History'.)

Use the 'Normalise' button to automatically change the allocation factors to obtain a total allocation of 1.0. This is done by raising or lowering all the factors by the same proportion as required.

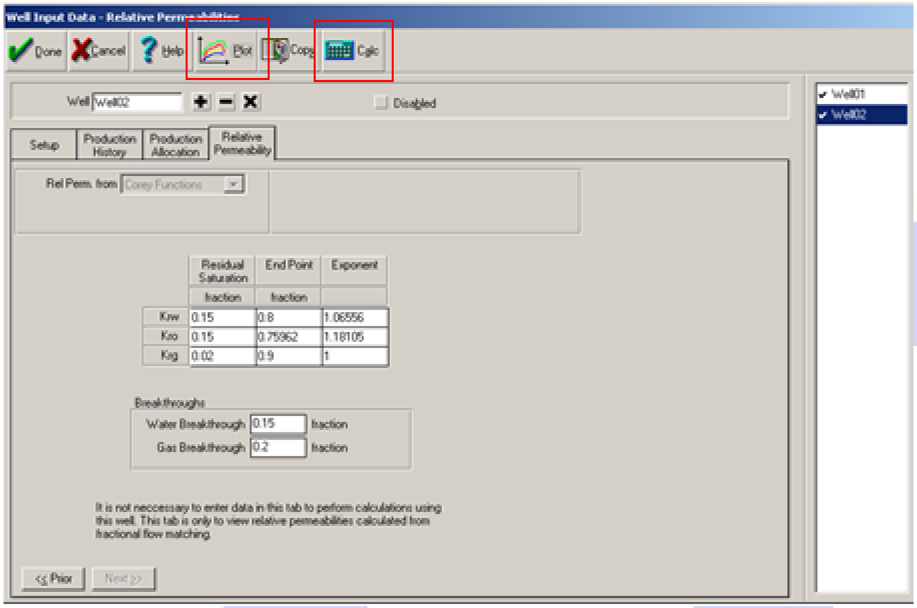
- ➲ **The allocation factor requires the user to decide the fraction of production that came from each layer. The Reservoir Allocation tool can also be used to determine reservoir production allocation, taking into account the IPR of each layer as well as the rate of depletion.**

2.4.4.1.5 Relative Permeability

The modelling of wells in the system has been defined in prior chapters (Wells Data 425).

This model has so far involved: defining the well type, entering historical data and defining the allocation fraction.

There is one final step, (introduced in **IPM version 7)**, the relative permeability for each well can now be calculated from the historical data:


Well Input Data - Relative Permeabilities
Done
Cancel
Help
Plot
Copy
Calc
Setup
Production History
Production Allocation
Relative Permeability
<< Prior
Next >>
Well01
Well02

Well: Well02

☐ Disabled

Rel Perm. from: Corey Functions

	Residual Saturation	End Point	Exponent
	fraction	fraction	
Krw	0.15	0.8	1.06556
Kro	0.15	0.75962	1.18105
Krg	0.02	0.9	1

Breakthroughs

Water Breakthrough: 0.15 fraction

Gas Breakthrough: 0.2 fraction

It is not neccessary to enter data in this tab to perform calculations using this well. This tab is only to view relative permeabilities calculated from fractional flow matching.

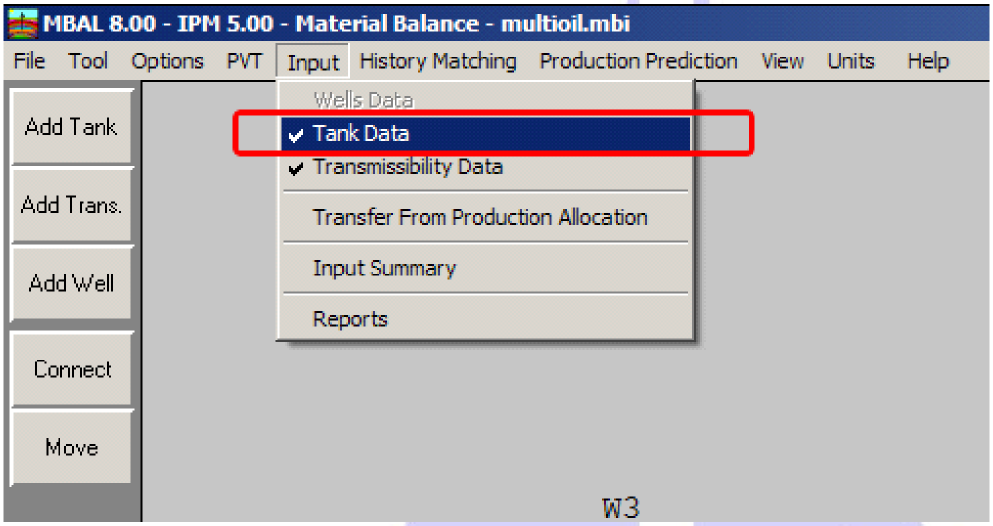
This allows the flow of each phase to the well to be defined (selecting the 'Calc' button) based on the historical data input by the user.

The 'Plot' button allows the relative permeability curves to be observed.

These curves can the be imported into GAP for future calculations within the integrated system.

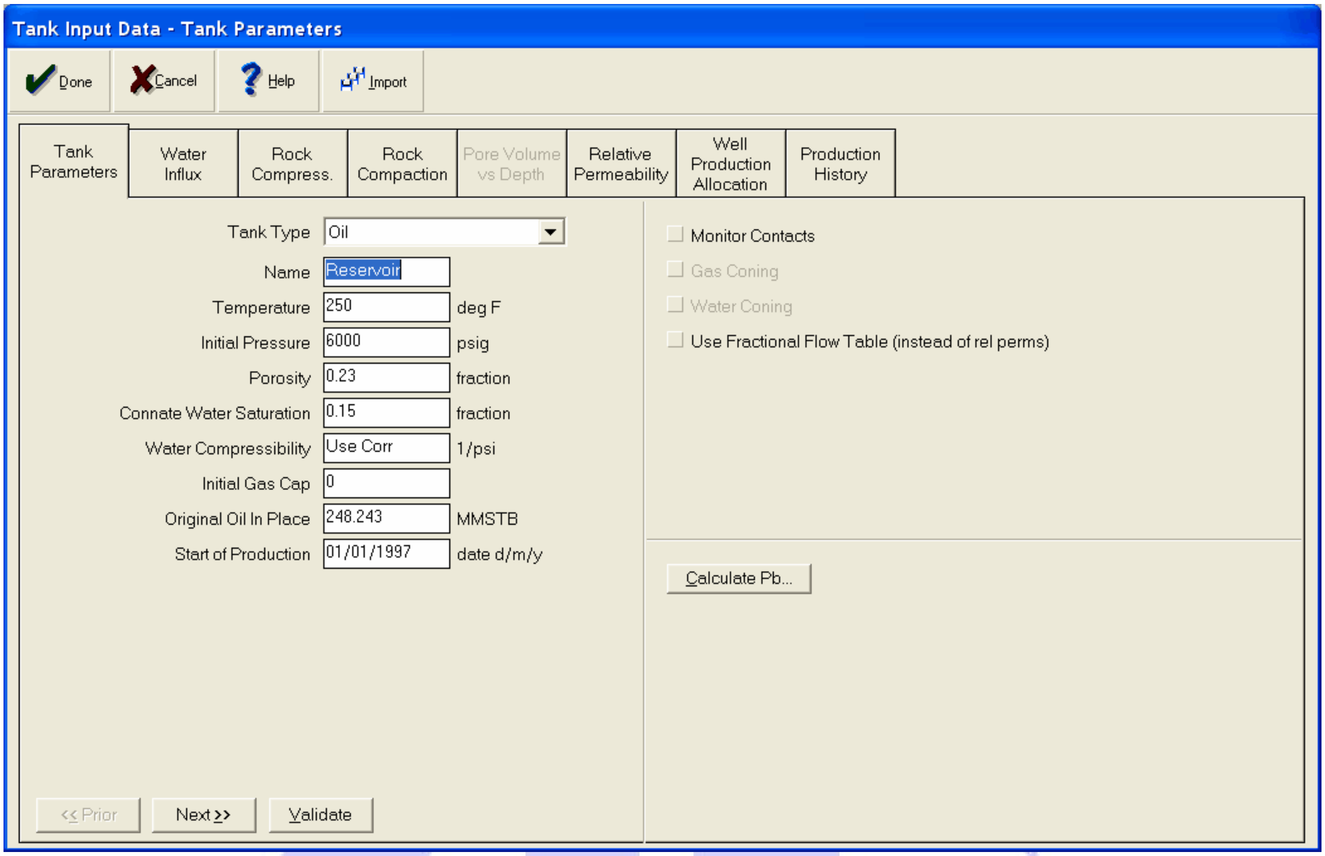
2.4.4.2 Tank Input Data

This section describes the options under:


MBAL 8.00 - IPM 5.00 - Material Balance - multioil.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Add Tank
Add Trans.
Add Well
Connect
Move
Wells Data
✓ Tank Data
✓ Transmissibility Data
Transfer From Production Allocation
Input Summary
Reports
W3

2.4.4.2.1 Tank Parameters

This input data sheet screen is used to define the different tank parameters that are applied in the calculations.


Tank Input Data - Tank Parameters
Done
Cancel
Help
Import
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Well Production Allocation
Production History
Calculate Pb...
<< Prior
Next >>
Validate

Tank Type	Oil	
Name	Reservoir	
Temperature	250	deg F
Initial Pressure	6000	psig
Porosity	0.23	fraction
Connate Water Saturation	0.15	fraction
Water Compressibility	Use Corr	1/psi
Initial Gas Cap	0	
Original Oil In Place	248.243	MMSTB
Start of Production	01/01/1997	date d/m/y

☐ Monitor Contacts
☐ Gas Coning
☐ Water Coning
☐ Use Fractional Flow Table (instead of rel perms)

Input Fields

Tank type	For the 'General' fluid model, this option can be used to specify the tank as predominantly oil or condensate. This will affect how the input data is specified and define the wetting phase used in the relative permeability calculations. If necessary, this option allows the definition of a water tank. A water tank can be used to connect several hydrocarbon tanks to the same aquifer
Temperature	The reservoir models are isothermal. Although each reservoir model can have a different temperature from the others, the temperature will remain constant throughout the calculations
Initial Pressure	Defines the original pressure of the reservoir and is the starting point of all the calculations ➲ In an oil tank with an initial gas cap, make sure the initial pressure of t equals the Bubble Point pressure calculated at reservoir temperature PVT section of this program. The “Calculate Pb” button will display the point of the fluid for the reservoir temperature entered.
Porosity	The porosity entered here will be used in the rock compressibility calculations if the correlation option is selected the compressibility page

Connate Water Saturation	This parameter is used in the pore volume and compressibility calculations
Water Compressibility	(This parameter is optional) The user has the choice of entering water compressibility or allowing the internal correlations within the program to be used. The same is used for the aquifer model connected to this reservoir model. If a number is entered, the program will assume the water compressibility does not change with pressure. ➲ When the water compressibility is specified, the program back calculate water FVF from the compressibility. In this case, the water FVF correlat and displayed in the PVT section is ignored. This is to avoid inconsisten between different computations in the program, some using the water compressibility (Graphical and Analytical Methods); the others using the change of water FVF (Simulation and Prediction). If left blank, a 'Use Corr' message is displayed which indicates the program will do one of the following during the calculations:: • If the PVT Tables are in use, and if some values have been entered in the water FVF column of the PVT Tables, the program will interpolate/ extrapolate from the PVT tables. • If the PVT Tables are not used, or if there is no data for this parameter in the PVT tables, the program will use an internal correlation to evaluate the water compressibility as a function of temperature, pressure and salinity. The correlation results can be read in the calculation screens or reports.
Initial Gas Cap	(Oil Tanks Only) Defines the original ratio of the volumes occupied by gas and oil at tank conditions. It can be defined as m = (G * Bgi) / (N * Boi) where G and N are volume at surface. This parameter will be disabled if the Initial Pressure is above the Bubble Point Pressure calculated by the PVT section at Tank Temperature
Initial Oil Leg	(CONDENSATE Tanks Only) Defines the original ratio of the volumes occupied by the gas and oil at tank conditions. It can be defined as n = (N * Boi) / (G * Bgi) where G and N are volume at surface. Note that an initial oil leg can only be used if the General fluid model has been selected in the Options menu
Original Oil/Gas in Place	This is generally the main parameter of interest. If the History Matching facility of this program is not going to be utilised, a value as accurate as possible must be entered

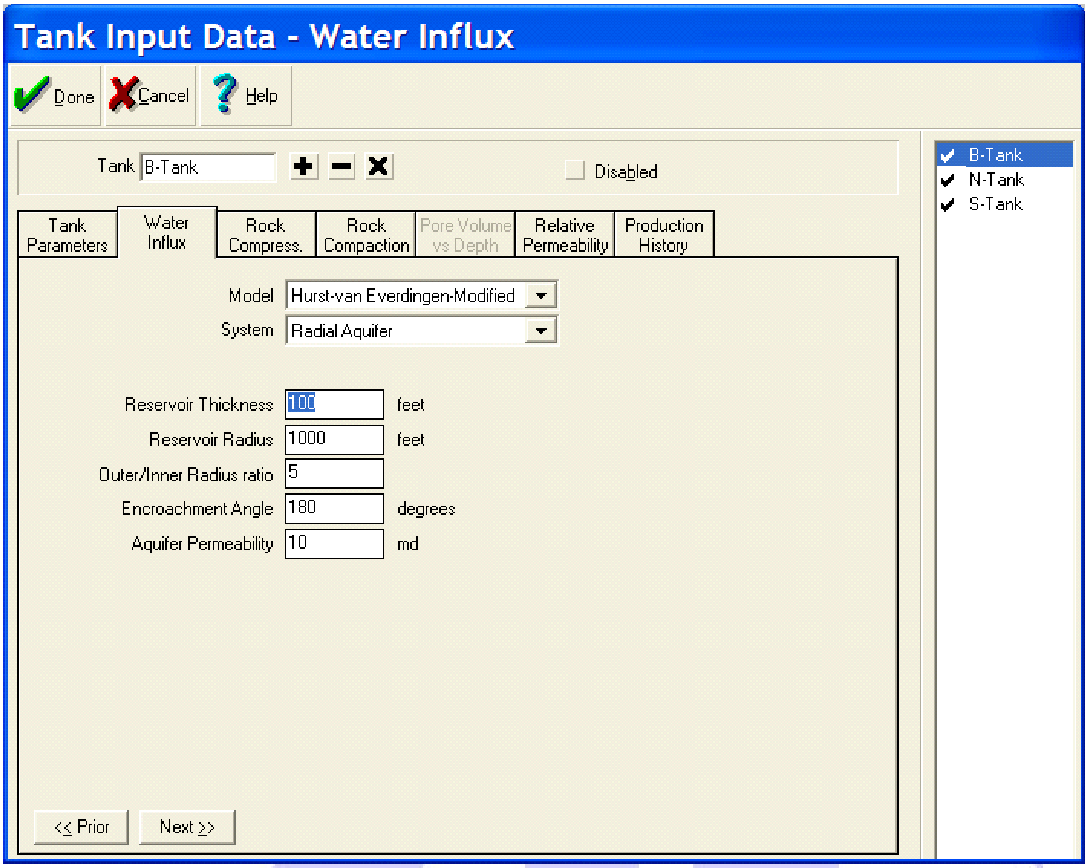
Start of Production	The point in time when production started
Permeability	(Gas/Water Coning Only) This is only required if the gas coning option for oil tanks is switched on and refers to the average radial permeability of the tank
Anisotropy	(Gas/Water Coning Only) This is only required if the gas coning option for oil tanks is switched on. This is ratio of the vertical permeability and the average radial permeability of the tank
Monitor **Fluid Contacts**	Select this option if the program is to calculate the depth of the gas/oil, oil/water or gas/water contacts. A check indicates the option is 'On'. If this option is selected, it will be necessary to fill in the table in the 'Pore Volume Fraction Vs Depth' tab of the Tank Input dialogue. In predictive mode, this table allows the triggering of gas/water breakthrough on the depth of the fluid contacts instead of the phase saturations. (See the Well Type Definition dialogue box). De-select the option if no fluid contact depth calculation is to be performed or the required data is not available. See section below on the method used to model fluid contacts
Dry Gas Producers	(oil fields only) Select this option, if the primary gas cap is being produced by dry gas producer wells. It must also be selected if the Use Total Saturations option is to be used - see below for more information on this option. When this option is selected, the initial pore volume is considered to be the gas cap + the oil leg. Therefore the initial gas saturation in the pore volume is: $(1-Swc) * m / (1 + m)$ with $m = (G*Bgi) / (N*Boi)$. MBAL is therefore applying material balance to the total pore volume (oil leg plus gas cap) so that it can successfully model oil being pushed into the initial gas cap. If oil never encroaches into the initial gas cap, this option will make no difference to the results
Gas Coning	(oil fields only) This option can only be selected if 'Use Total Saturations' and 'Monitor Contacts' are also selected. If selected,it will be possible to select gas coning for any of the layers connected to this tank in the Production Prediction - Well Definition dialogue. If gas coning is used, the production prediction will calculate the GOR for a layer using a gas coning model rather than using the relative permeability. Water cut will still be calculated from the relative permeability curves. The gas coning model can be matched for each layer in the Production Prediction - Well Definition dialogue. The gas coning model is based on reference 32, see Appendix B

Water Coning	(oil fields only) If this option has been selected, water coning for any of the layers connected to this tank can be modelled in the Production Prediction - Well Definition dialogue. If water coning is used, the production prediction will calculate the WC for each layer using a water coning model rather than using the relative permeability while the GOR will still be calculated from the relative permeability curves. The water coning model can be matched for each layer in the Water Coning Matching dialogue. The water coning model is based on "Bournazel-Jeanson, Society of Petroleum Engineers of AIME, 1971". The time to breakthrough is proportional to the rate meaning that for low rates, breakthrough may never occur. After breakthrough, the Wc develops roughly proportionally to the log of the Np, to a maximum water cut
Gas Storage	(gas fields only) This option allows gas injection into a water or oil tank to modelled. The 'Total Pore Volume' for the gas storage tank will need to be specified. If there is no gas originally in the tank, then the defined gas in place value can remain at zero, otherwise enter the amount but ensure that the downhole GIP is not greater than the total pore volume. During prediction a scheme of injection and production to simulate the injection of gas for storage and its later retrieval can be modelled. MBAL will use the total saturations to determine the relative permeabilities so it is likely that water breakthroughs will be required on production wells, particularly if the amount of gas injected is small with respect to the total pore volume
Model water pressure gradient	(gas fields only) This model allows the effect of changing pressure on the residual gas saturation trapped behind the advancing water front to be accounted for. A gas FVF for the residual gas saturation is determined by taking the tank pressure to be the pressure at the current GWC. We then calculate the pressure from the current GWC down to the initial GWC using the density of the water. The changing pressure is then used to give the gas FVF of the trapped gas. Within the material balance calculations we take into account the gas trapped behind the water as a separate phase using the Bg as calculated above. We assume a constant Sgr so we assume that if the pressure drops within the water zone, any gas that expands beyond the Sgr will immediately move back to the gas cap. 'Monitor Contacts' must also be selected if GWC is to be observed
Total Pore Volume	(Gas Storage Only) The total pore volume defines the volume available for gas storage, i.e. the

	total downhole volume of pores that can be used for the function of storage. If an Original Gas in place (OGIP) is specified this is said to be the volume already contained in the total pore volume at initial conditions. Thus the total pore volume must be higher or equal to the OGIP by definition.
PVT Definition	(Multiple Tank Model Only) Select the PVT definition to use for this tank. If different PVT definitions are used for different tanks, MBAL treats them in a simple manner. When oil/gas/water moves from one tank to another, it immediately takes on the properties of the PVT definition associated with the tank into which the fluid is flowing. This method obviously has limitations if the fluid in the different PVT definitions is significantly different
Calculate Pb	(Oil tank only) Click this button to display a dialogue allowing the bubble point pressure to be calculated
Coalbed Methane	(gas fields only) Select this option if the reservoir is coalbed methane. See Coalbed Methane Introduction 332 for more information on this option. NOTE : If this option is selected then the OGIP is defined to be the initial free + adsorbed gas
Model Coal Permeability Variation	(only if Coalbed Methane option selected) Select this option if you wish to model variation of permeability for Coalbed Methane reservoirs and its effect on IPRs connected to this tank
Langmuir Isotherm	(only if Coalbed Methane option selected) Click this button to enter the Langmuir Isotherm 335 data which models gas adsorption
Coal Permeability Variation Model	(only if Model Coal Permeability Variation option selected) Click this button to enter a model to describe permeability variation in a Coalbed Methane reservoir 340 and its effect on IPRs connected to this tank

2.4.4.2.2 Water Influx

This screen is used to define the type and properties of an aquifer, if one is present. To access the water influx screen, choose Input|Tank Data and select the 'Water Influx' tab. A dialogue box as seen below is displayed:


Tank Input Data - Water Influx
Done
Cancel
Help
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
<< Prior
Next >>
☑ B-Tank
☑ N-Tank
☑ S-Tank

Tank: B-Tank

☐ Disabled

Model: Hurst-van Everdingen-Modified

System: Radial Aquifer

Reservoir Thickness: 100 feet

Reservoir Radius: 1000 feet

Outer/Inner Radius ratio: 5

Encroachment Angle: 180 degrees

Aquifer Permeability: 10 md

Input Fields

The particular input variables depend of the model, system and boundary type selected. A description of each variable is only listed if there is some useful additional explanation. Otherwise please refer to Appendix C (Aquifer_Models) which describes the use of each variable within the aquifer functions.

Model	Select one of the different aquifer models available with this program. Choose **none** if no water influx is to be included. The remainder of the screen will change with respect to the aquifer model selected
System	Defines the type of flow prevailing in the reservoir and aquifer system
Boundary	Defines the boundary for linear and bottom drive aquifers. Constant pressure means that the boundary between the hydrocarbon volume and the aquifer is maintained at a constant pressure. Sealed boundary means that the aquifer has only a finite extent as the aquifer boundary (not in contact with the hydrocarbon volume) is sealed. Infinite acting means that the aquifer is effectively infinite in extent
Use Constant Compressibility	Several of the aquifer models use water and rock compressibilities in the aquifer calculations. Normally MBal will use the compressibilities calculated at the current tank pressure. However, if this option is selected,

	then the compressibilities calculated at the initial tank pressure will be used in the calculations

Radial Aquifers

Reservoir Thickness	This parameter is used to calculate the surface of encroachment of the aquifer by multiplying it with the radius and encroachment angle
Reservoir Radius	This parameter is used to calculate the surface of encroachment of the aquifer by multiplying it with the thickness and encroachment angle
Outer/Inner Radius Ratio	Defines the ratio of the outside radius (aquifer radius) to the inside radius (reservoir radius)
Encroachment Angle	Defines the portion of the reservoir boundary through which the aquifer invades the reservoir
Aquifer Permeability	Defines the total permeability within the aquifer pore volume

Linear Aquifers

Reservoir Thickness	This parameter is used to calculate the surface of encroachment of the aquifer by multiplying it with the reservoir width
Aquifer Volume	Defines the amount of fluid in the aquifer. It is used to calculate the aquifer fluid expansion when reservoir pressure declines
Reservoir Width	This parameter is used to calculate the surface of encroachment of the aquifer by multiplying it with the reservoir thickness

Bottom Drive Aquifers

Aquifer Volume	Defines the amount of fluid in the aquifer. It is used to calculate the aquifer fluid expansion when reservoir pressure declines
Vertical Permeability	Defines the aquifer vertical permeability

Enter, or modify the data as required. Then go to the next tab or press ***done*** to accept the changes or ***Cancel*** to quit the screen and ignore any changes.

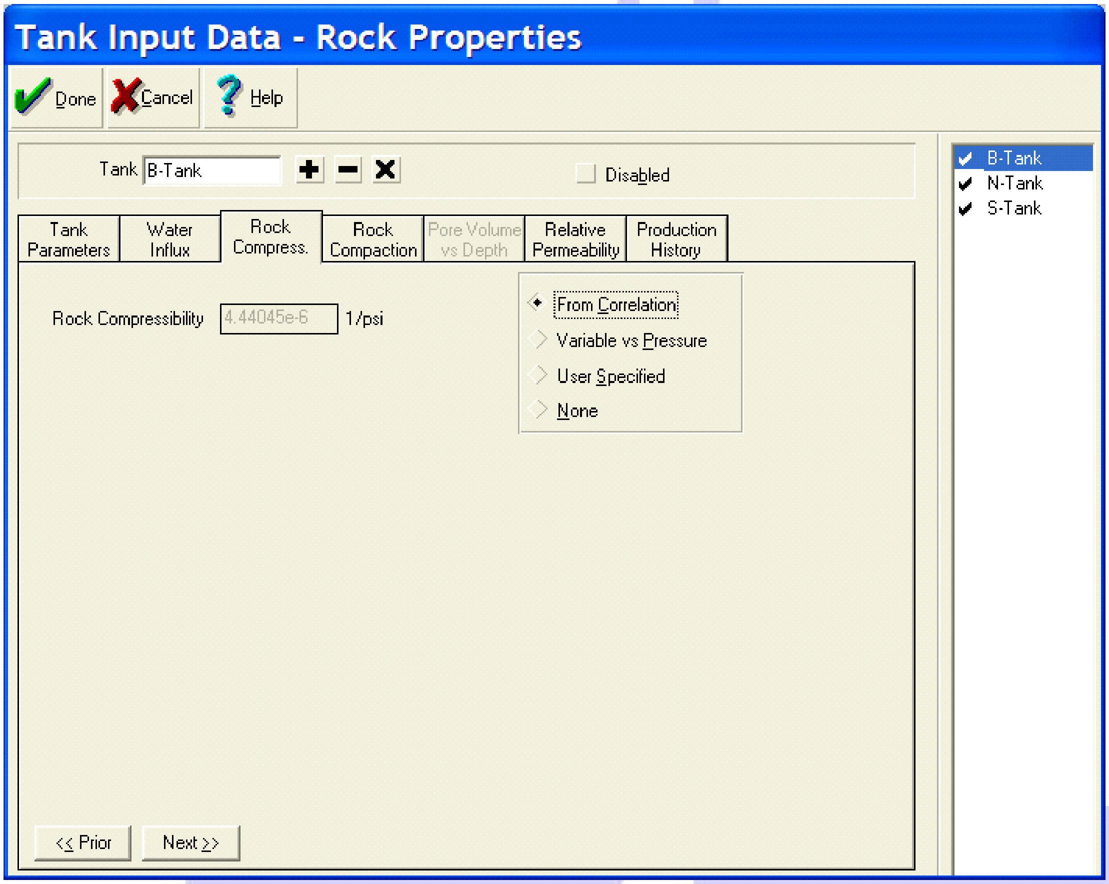
See Appendix section on (Aquifer_Models) for details of the water influx equations.

Tank Control Fields

See Tank Control Fields for more information.

2.4.4.2.3 Rock Compressibility

This screen is used to define the rock properties. To access this screen, choose Input|Tank Data and select the 'Rock Compressibility' tab. The following screen will be displayed:


Tank Input Data - Rock Properties
Done
Cancel
Help
+
−
✕
☐ Disabled
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
● From Correlation
○ Variable vs Pressure
○ User Specified
○ None
<< Prior
Next >>
✓ B-Tank
✓ N-Tank
✓ S-Tank

Tank: B-Tank

Rock Compressibility: 4.44045e-6 1/psi

Input Fields

<table>
<tr><td>From Correlation</td><td>If this option is selected, the program will use an internal correlation to evaluate the compressibility as a function of the porosity. The internal correlation used is expressed as:
if porosity > 0.3 then $C_f = 3.2e^{-6}$
if porosity < 0.3 then $C_f = 3.2e^{-6} + ((0.3 - porosity)^{2.415})* 7.8e{-05}$</td></tr>
<tr><td>Variable vs Pressure</td><td>If this option is selected; rock compressibility values varying with pressure can be entered. There are two ways of defining the compressibility: on original volume and on tangent.
<table><tr><td>On Original Volume</td><td>The Cf at pressure P and V is defined using the formula,
$C_f = -\frac{1}{V_i}\frac{(V - V_i)}{(P - P_i)}$
Where V_i and Pi are the pore volume and pressure at initial</td></tr></table></td></tr>
</table>

<table>
<tr><td></td><td><table>
<tr><td></td><td>conditions. This formulation means that the results are not dependant on the time steps selected</td></tr>
<tr><td>On Tangent</td><td>The Cf at pressure P and V is defined using the formula:
$C_f = -\frac{1}{V}\frac{dV}{dP}$
where dV/dP is the derivative at pressure P.
The program ALWAYS uses the original volume Cf so this column must be entered to make the dataset valid. However if the only available Cf value is based on tangents, this column could be entered instead and then selecting the Calculate button will calculate the Cf based on original volume</td></tr>
</table></td></tr>
<tr><td>User Defined</td><td>If this option is selected, the user will need to enter the formation compressibility and the program will assume that the compressibility does not change with pressure</td></tr>
<tr><td>None</td><td>The rock compressibility is neglected. This option can be used for testing purpose to verify the impact of the pore volume compressibility on the overall reservoir response. This is equivalent to a Cf=0.0</td></tr>
</table>

The pore volume is calculated using PV = PVi (1.0 - Cf(Pi-P))

Tank Control Fields

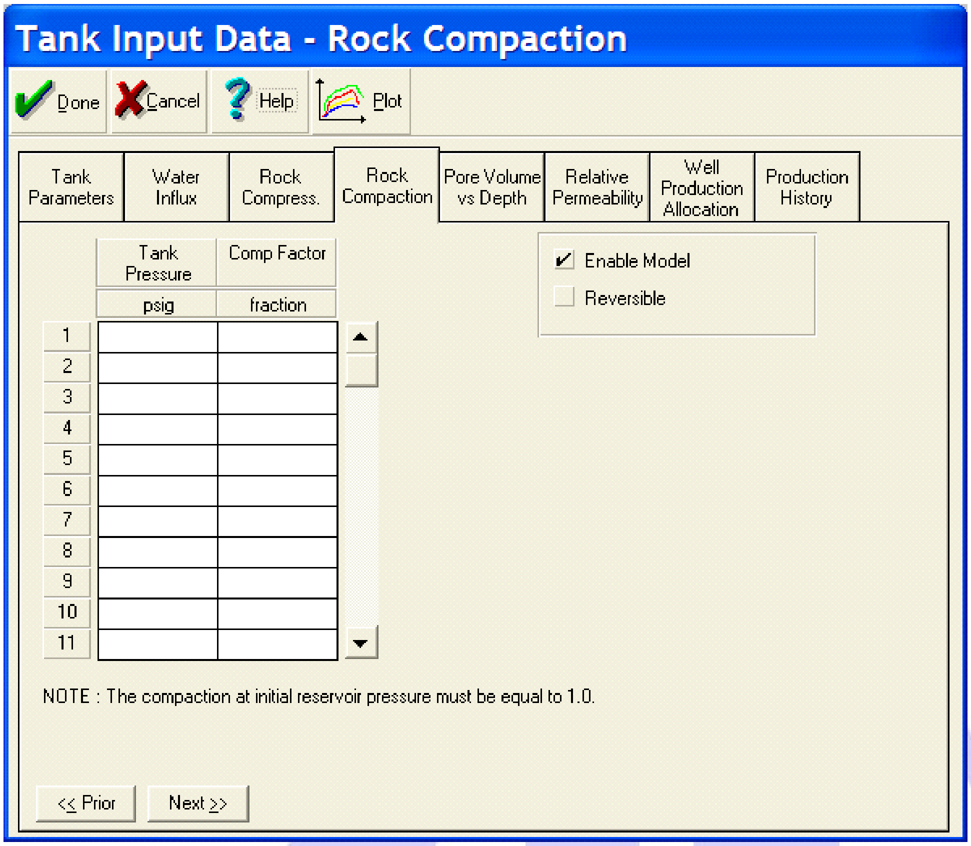
See Tank Control Fields for more information.

Command Buttons

Plot	This option is available if Variable vs Pressure is selected. It will display a plot of the table data entered
Calculate	This option is available if Variable vs Pressure is selected. It can be used to calculate the Cf based on original volume from the Cf based on tangents (and visa-versa)

2.4.4.2.4 Rock Compaction

Use this tab to define the Rock Compaction. This model can be used to help match to reservoir simulator data.


Tank Input Data - Rock Compaction
Done
Cancel
Help
Plot
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Well Production Allocation
Production History
Tank Pressure
Comp Factor
psig
fraction
1
2
3
4
5
6
7
8
9
10
11
<< Prior
Next >>

☑ Enable Model
☐ Reversible

NOTE : The compaction at initial reservoir pressure must be equal to 1.0.

Input Fields

Enable	Select this option to enable the model
Reversible	Select this option to make the model reversible. If this option is left unselected, the pore volume will not increase back to the original volume if the reservoir re-pressurises. Enter the P vs compaction factor. The pore volume at each pressure will then be calculated using PV = PVi * Compaction Factor(P) See Table Data Entry for more information on entering the compaction data. **WARNING**: The program will allow both the rock compaction and rock compressibility model at the same time. If both models are used the program calculates the PV using: PV = PVi *(1.0 - Cf(Pi-P))*Compaction Factor(P)

See Tank Control Fields for more information.

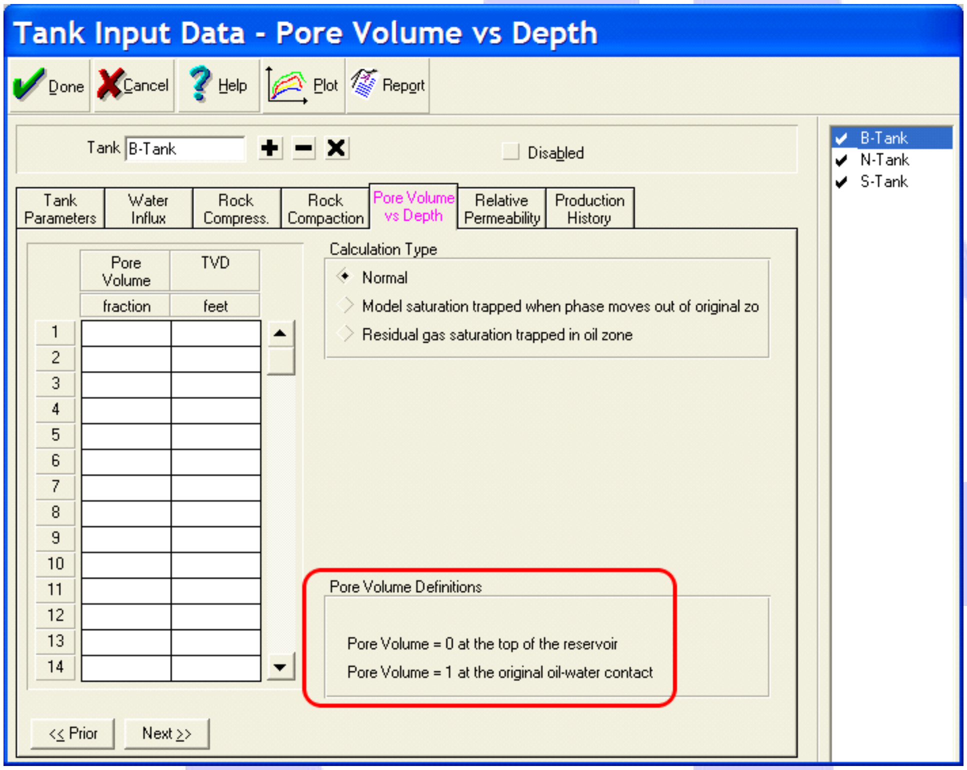
Command buttons

Plot	This option is available if Variable v Pressure is selected. It will display a plot of the table data entered
Calculate	This option is available if Variable v Pressure is selected. It can be used to

	calculate the Cf based on original volume from the Cf based on tangents (and vice-versa)

2.4.4.2.5 Pore Volume vs. Depth

This screen is used to define the 'Pore Volume vs. Depth'. To access this screen, choose Input| Tank Data and select the Pore Volume vs. Depth tab. A dialogue box as seen below will be displayed:


Done
Cancel
Help
Plot
Report
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
Pore Volume
TVD
fraction
feet
1
2
3
4
5
6
7
8
9
10
11
12
13
14
<< Prior
Next >>
✓ B-Tank
✓ N-Tank
✓ S-Tank

Tank Input Data - Pore Volume vs Depth

Tank B-Tank

☐ Disabled

Calculation Type

● Normal

○ Model saturation trapped when phase moves out of original zo

○ Residual gas saturation trapped in oil zone

Pore Volume Definitions

Pore Volume = 0 at the top of the reservoir

Pore Volume = 1 at the original oil-water contact

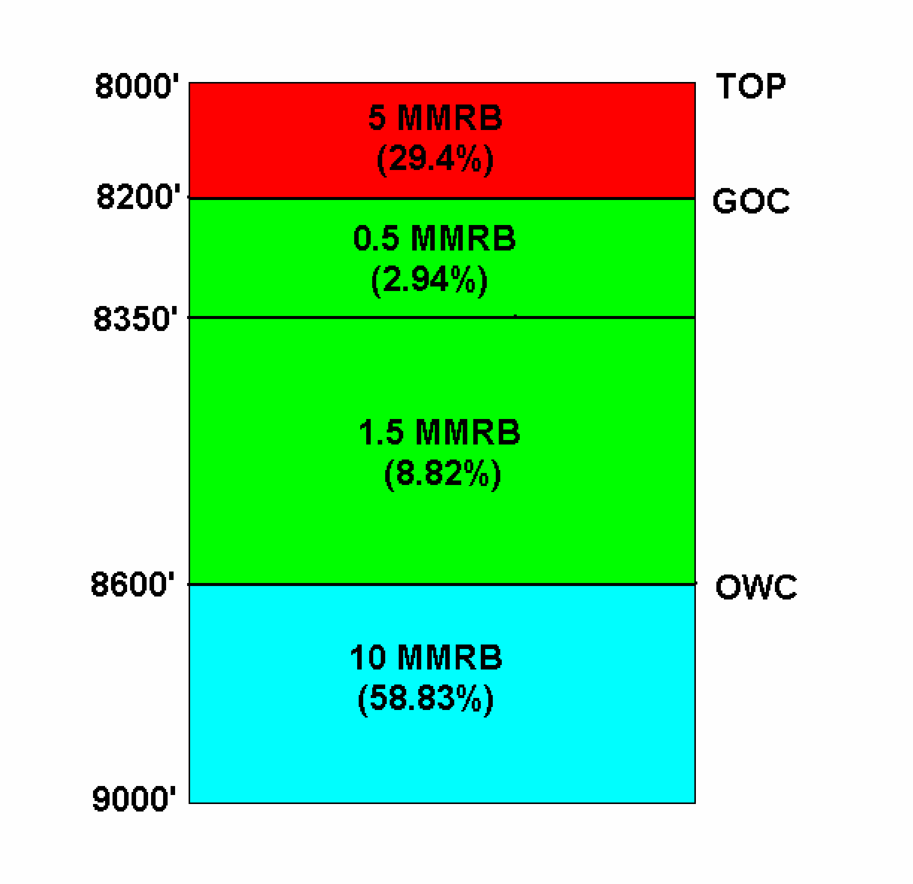
Material Balance analysis for reservoirs is based on treating the system as a dimensionless tank. The traditional approach does not allow consideration of fluid contact depths and their movements, (GOC or OWC or GWC) as no geology is provided.

In **MBAL** the addition of Pore Volume vs. Depth table introduces a means of allowing contact movements. Pore volume is directly related to saturations of phases in the reservoir and these in turn are related to a given depth through this table.

Let us assume a situation where an aquifer is providing support to an oil reservoir. The aquifer will provide water that will encroach in the tank, thus increasing the water saturation. In classical material balance calculations, the water saturation in the tank will increase as a single number (no variation of Sw in the reservoir). However, if the increase in water saturation is related to a pore volume fraction, then the increase in the OWC can be calculated based on the PV vs. Depth table.

This tab is enabled only if the *Monitor Contacts* option in the Tank Parameters data sheet has been activated. The table displayed is used to calculate the depth of the different fluid contacts. ***This table must be entered for variable PVT tanks***.

The definitions for entering 'Pore Volume' fractions are displayed in the 'Definitions' section in this page as shown above. The definitions will automatically change depending on the fluids present in the tank at initial conditions. Some details are provided below:

Pore Volume vs. Depth for Oil Reservoirs	**Below GOC:** Pore Volume Fraction = (pore volume from top of oil leg to the depth of interest)/ (total oil leg pore volume) **Above GOC:** Pore Volume Fraction = - (pore volume from top of oil leg to depth of interest)/ (total gas cap volume) For example, for the case below:  8000' 8200' 8350' 8600' 9000' TOP GOC OWC 5 MMRB (29.4%) 0.5 MMRB (2.94%) 1.5 MMRB (8.82%) 10 MMRB (58.83%) Total gas cap pore volume = 5 MMRB

Total oil leg pore volume = 2 MMRB
Oil pore volume fraction at 8200' = 0.0
Oil pore volume fraction at 8350' from GOC = 0.5 / 2 = 0.25
Oil pore volume fraction at 8600' from GOC = 2 / 2 = 1.0
Gas pore volume fraction at 8000' = - 5 / 5 = -1.0

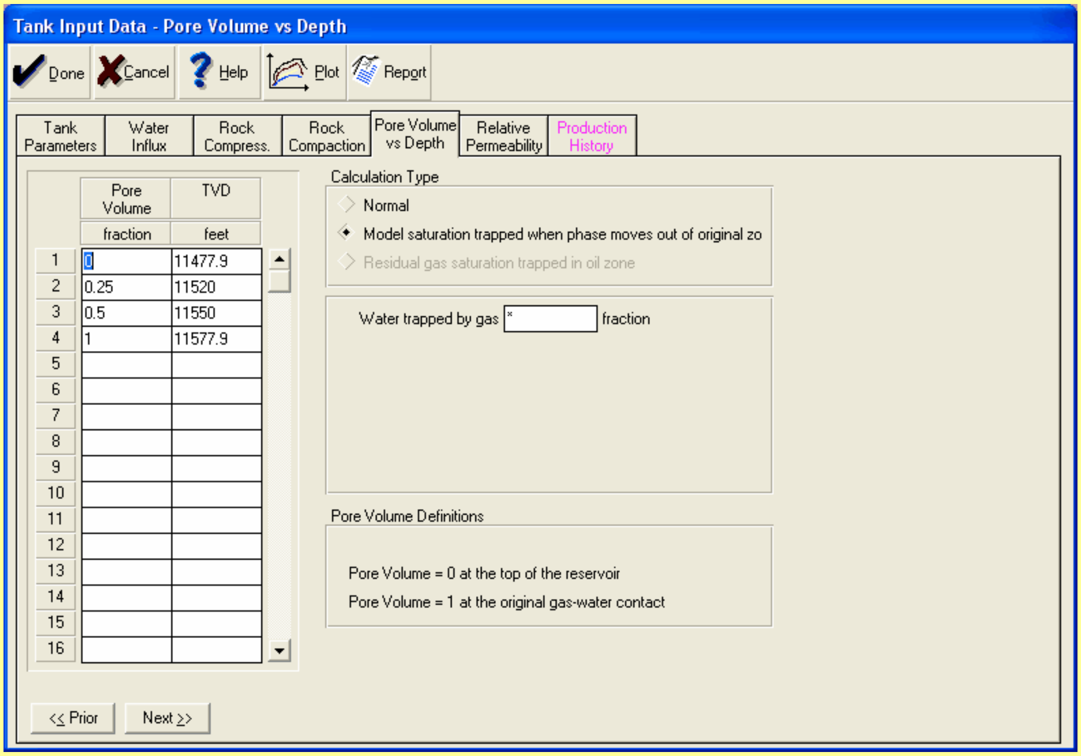
So enter PV vs. Depth table:

PV	TVD
-1.0	8000
0.0	8200
0.25	8350
1.0	8600

Pore Volume vs Depth for Dry & Wet Gas Models.

The data here would be identical to that for an oil reservoir.

In the case of a Dry and Wet Gas Model only two options would be available for the user as shown below:


Tank Input Data - Pore Volume vs Depth
Done
Cancel
Help
Plot
Report
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
<< Prior
Next >>

	Pore Volume	TVD
	fraction	feet
1	0	11477.9
2	0.25	11520
3	0.5	11550
4	1	11577.9

Calculation Type
○ Normal
● Model saturation trapped when phase moves out of original zo
○ Residual gas saturation trapped in oil zone

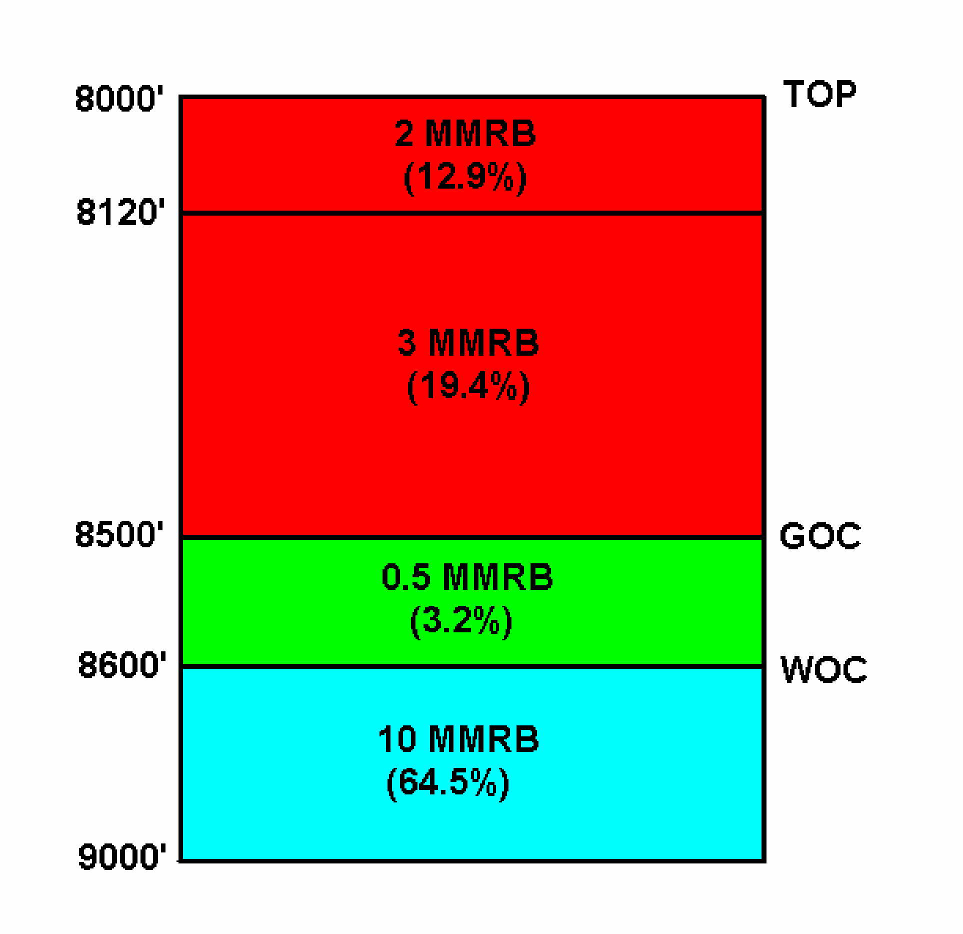
Water trapped by gas * fraction

Pore Volume Definitions
Pore Volume = 0 at the top of the reservoir
Pore Volume = 1 at the original gas-water contact

NORMAL: the pore volume vs. depth table to calculate the corresponding depth

Model Saturation Trapped when Phase Moves out of Original Zone:

	This option for the water trapped by GAS is applicable when the fluid contacts start to encroach back into the original phase. For example: 1) If we consider a GWC originally at 5000 ft 2) Then over time water encroaches into the reservoir so that GWC rises to 4950 ft 3) During this time, the water trapped by gas is not considered. It is assumed that the saturation trapped behind is the {residual saturation of the phase + the sweep efficiency if defined) 4) If the GWC starts to fall again from 4950 ft to 4980 ft, then this is where the water trapped by gas saturation will be used. 5) In this case, the saturation of water trapped between 4950 ft and 4980 ft is the value specified in the column. If the objective is to take into account the saturation of the gas phase left behind as the water encroaches into the gas reservoir, then this can be taken into account using the SWEEP EFFICIENCY defined in the Relative Permeability tab.
Pore Volume vs. Depth For Gas/ condensate Reservoirs	**Above GOC:** Pore Volume Fraction = (pore volume from top of gas cap to the depth of interest)/ (total gas cap pore volume) **Below GOC:** Pore Volume Fraction = 1.0 + (pore volume from top of oil leg to depth of interest)/ (total oil leg volume) For example, for the case below:

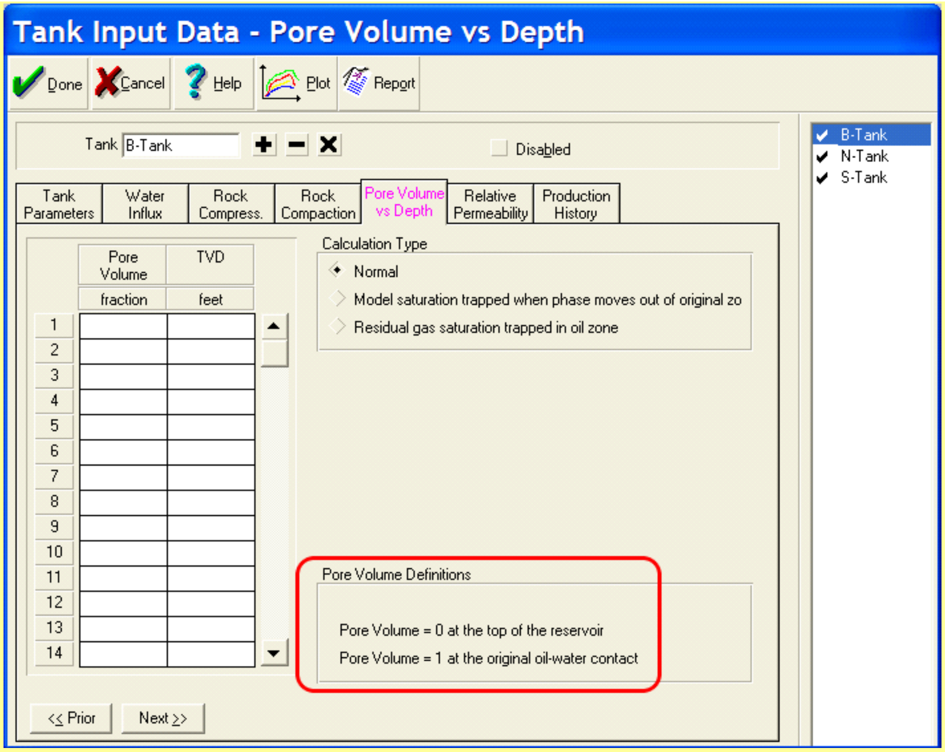

8000'
TOP
2 MMRB
(12.9%)
8120'
3 MMRB
(19.4%)
8500'
GOC
0.5 MMRB
(3.2%)
8600'
WOC
10 MMRB
(64.5%)
9000'

Total gas cap pore volume = 5 MMRB
Total oil leg pore volume = 0.5 MMRB
Gas pore volume fraction at 8000' = 0.0
Gas pore volume fraction at 8120' from GOC = 2 / 5 = 0.4
Gas pore volume fraction at 8500' from GOC = 5 / 5 = 1.0
Oil pore volume fraction at 8600' = 1 + 0.5 / 0.5 = 2.0

So the PV vs. Depth table can be entered as:

PV	TVD
0.0	8000
0.4	8120
1.0	8500
2.0	8600

There are three calculation methods related to this option:


Tank Input Data - Pore Volume vs Depth
Done
Cancel
Help
Plot
Report
Tank B-Tank
Disabled
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
Pore Volume
TVD
fraction
feet
1
2
3
4
5
6
7
8
9
10
11
12
13
14
<< Prior
Next >>
B-Tank
N-Tank
S-Tank

Calculation Type

● Normal

○ Model saturation trapped when phase moves out of original zo

○ Residual gas saturation trapped in oil zone

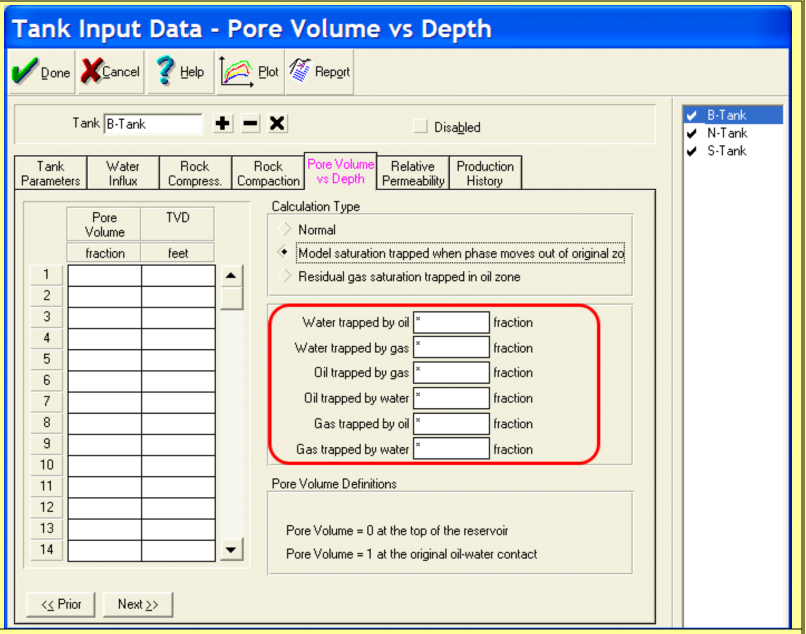
Pore Volume Definitions

Pore Volume = 0 at the top of the reservoir

Pore Volume = 1 at the original oil-water contact

Calcula
Type

Normal	The method of calculating the fluid contacts depends on the fluid type of the reservoir. In each case we calculate the pore volume swept by the appropriate phase. We then use the pore volume vs. depth table to calculate the corresponding depth
Model Saturation trapped when phase moves out of original zone	This method uses the same rules as the old method for the residual saturations of the phases in their original locations i.e. the Sgr in the original gas cap and the Sor in the original oil leg. However, when a phase invades Pore Volume originally occupied by another phase, then a given saturation can be set as trapped, i.e. left behind. This can effectively be seen as “sweep efficiency” with a lot of flexibility in specifying the saturations trapped by each phase invading the pore volume originally occupied by a different phase:

	 Tank Input Data - Pore Volume vs Depth Done Cancel Help Plot Report Tank B-Tank ☐ Disabled ☑ B-Tank ☑ N-Tank ☑ S-Tank Tank Parameters / Water Influx / Rock Compress. / Rock Compaction / Pore Volume vs Depth / Relative Permeability / Production History Pore Volume (fraction) / TVD (feet), rows 1–14 Calculation Type ○ Normal ● Model saturation trapped when phase moves out of original zo ○ Residual gas saturation trapped in oil zone Water trapped by oil * fraction Water trapped by gas * fraction Oil trapped by gas * fraction Oil trapped by water * fraction Gas trapped by oil * fraction Gas trapped by water * fraction Pore Volume Definitions Pore Volume = 0 at the top of the reservoir Pore Volume = 1 at the original oil-water contact << Prior Next >>
Residual Gas saturation trapped in oil zone (oil tank only)	In the normal calculations, as soon as the pressure drops below the bubble point, the gas saturation starts increasing immediately. If this option is activated, then the gas will remain in the oil pore volume until the critical gas saturation is reached. Any further gas evolving out of the oil will create a gas cap

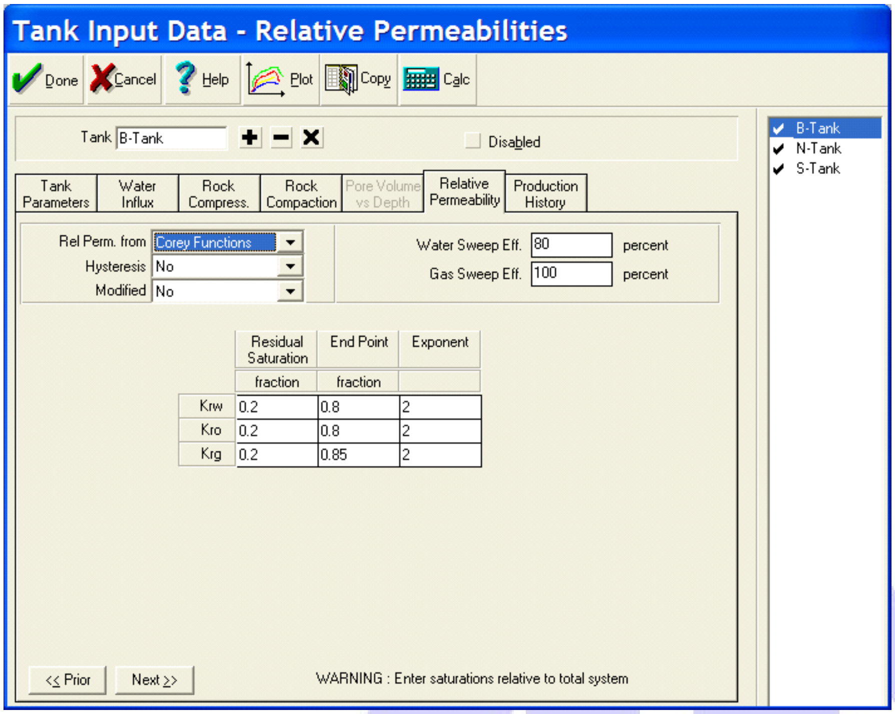
2.4.4.2.6 Relative Permeability / Fractional Flow Tables

There are two available methods to define the fluid behaviour during the prediction:

Entry of relative permeability values	When running a prediction in MBAL, the; GOR, WC, WGR and CGR are determined with the use of the user-defined relative permeabilities. These relative permeabilities are used to define; kro, krg and krw, which are then used to determine the mobility ratios which are in turn used to defined the GOR, WC etc. So relative permeabilities are required for production prediction and multi-tank history matching
Import of fractional flow tables	**(Introduced in IPM 7.0)** This method allows the user to import 'Fractional Flow' information directly

Entry of Relative Permeability Values

This screen defines the 'Residual Saturations' and the different phase 'Relative Permeabilities':


Tank Input Data - Relative Permeabilities
Done
Cancel
Help
Plot
Copy
Calc
Disabled
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
B-Tank
N-Tank
S-Tank
<< Prior
Next >>

Tank B-Tank

Rel Perm. from Corey Functions
Hysteresis No
Modified No

Water Sweep Eff. 80 percent
Gas Sweep Eff. 100 percent

	Residual Saturation	End Point	Exponent
	fraction	fraction	
Krw	0.2	0.8	2
Kro	0.2	0.8	2
Krg	0.2	0.85	2

WARNING : Enter saturations relative to total system

Input Fields

Water Sweep Efficiency	The 'Water Sweep Efficiency' is used in the calculation of the depth of the oil/water contact or gas/water contact. This parameter is only used in the calculation of the water contact and can be adjusted to match the measured depth when the production simulation does not reproduce the observations
Gas Sweep Efficiency **(oil reservoir only)**	The 'Gas Sweep Efficiency' is used in the calculation of the depth of the gas/oil contact. This parameter is only used in the calculation of the gas contact and can be adjusted to match the measured depth when the production simulation does not reproduce the observations
Rel Perm From	Allows selection of how the relative permeabilities are defined: • Corey Functions • User Defined input tables
Modified	Select from No, Stone 1 or Stone 2 modification. See Appendix B 483 for details of these modifications
Hysteresis	Select this option if hysteresis is to be applied. See section on Relative Permeability Hysteresis below for more information

Concerning the two modes of entering relative permeability curves, the two options are:

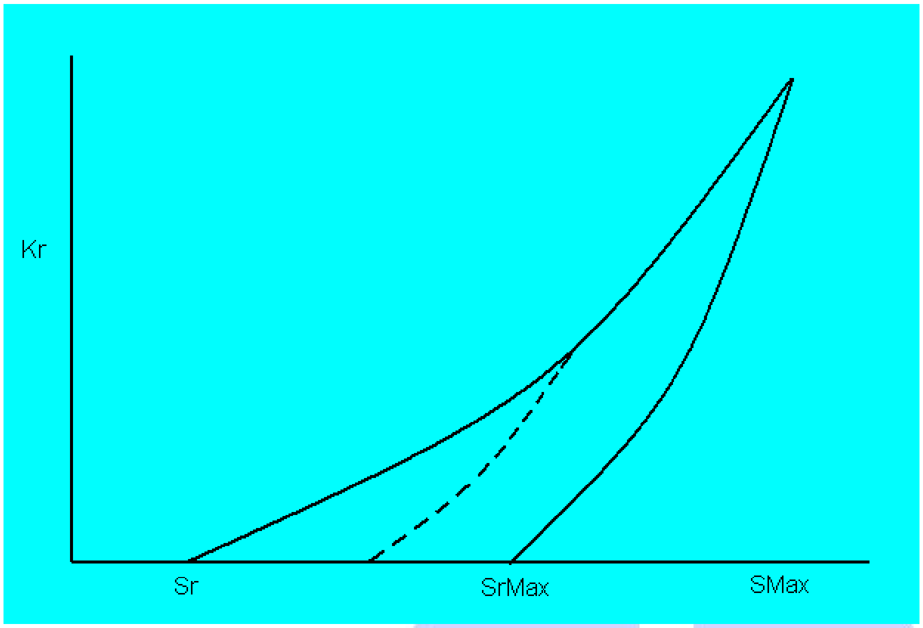
Corey Functions	The input data required are:

	Residual Saturations	Defines respectively: • The connate saturation for the water phase, • The residual saturation of the oil phase for gas flooding, • The critical saturation for the gas phase. • These saturations are used to calculate th of oil or gas 'by-passed' during a gas flooding
	End Points	Defines for each phase the relative permeab saturation maximum. For example for th corresponds to its relative permeability at Swc)
	Corey Exponents	Defines the shape of the rel perm curve betw and the end point. A value of 1.0 will give line. A value less than one will give a sha curves above the straight line. A value greater will give a shape that curves below the straigh
Table Entry	Enter the table data as requested. The program will interpret the residual saturation as the highest saturation with a relative permeability of zero	
	Maximum Residual Saturations	Enter the residual saturation that the system to if the reservoir reaches the maximum s See section on 'Relative Permeability H below for more information

2.4.4.2.6.1 Relative Permeability Hysteresis

The normal model assumes that the relative permeability curve follows the same path when the saturation increases as it does when the saturation decreases. However if the hysteresis option is activated, then a different relative permeability curve will be used as the saturation drops.

Consider the following relative permeability diagram:



The normal curve we enter begins at S=Sr where Kr=0.0 and rises to Kr=KrMax when S=SMax. If we had no hysteresis then the Kr would follow the same path when the saturation starts to fall.

However with hysteresis on, we also enter the SrMax value. As before, when the saturation starts to rise it follows the normal curve from Sr to SMax. Now if the saturation drops from SMax it will follow a different path. The curve it follows has the same shape as the normal path but is transformed so that the Kr=0.0 when S=SrMax.

Of course, in reality we rarely encounter a situation where the saturation increases to the maximum possible saturation before dropping again. It is more likely it will increase part of the way to the maximum possible saturation before dropping again. In this case we scale the SrMax by comparing the maximum possible saturation and the actual maximum saturation so far in the reservoir. This case is shown by the broken curve. If the saturation starts to rise again, it will follow the broken curve back to the normal curve and then continue up the normal curve.

2.4.4.2.6.2 Calculate Tables from Corey Functions

This feature can be used to calculate the equivalent relative permeability tables from the Corey functions.

The saturations of each phase at which the tables should be calculated need to be specified. There are two ways to specify the input saturations:

Automatic	Enter the start and end of the range of saturations required and the number of steps into which the range should be divided. Note that if the **Reset** button is selected, the start and end steps will be re-initialised to the residual saturations and maximum saturations
User Selected	Enter a list of the saturations that need to be calculated. Note that if the

	Reset button is selected, all of the user selected values will be removed

Then click **Done** to calculate the corresponding table. After completing the calculation, **MBAL** will display the calculated table.

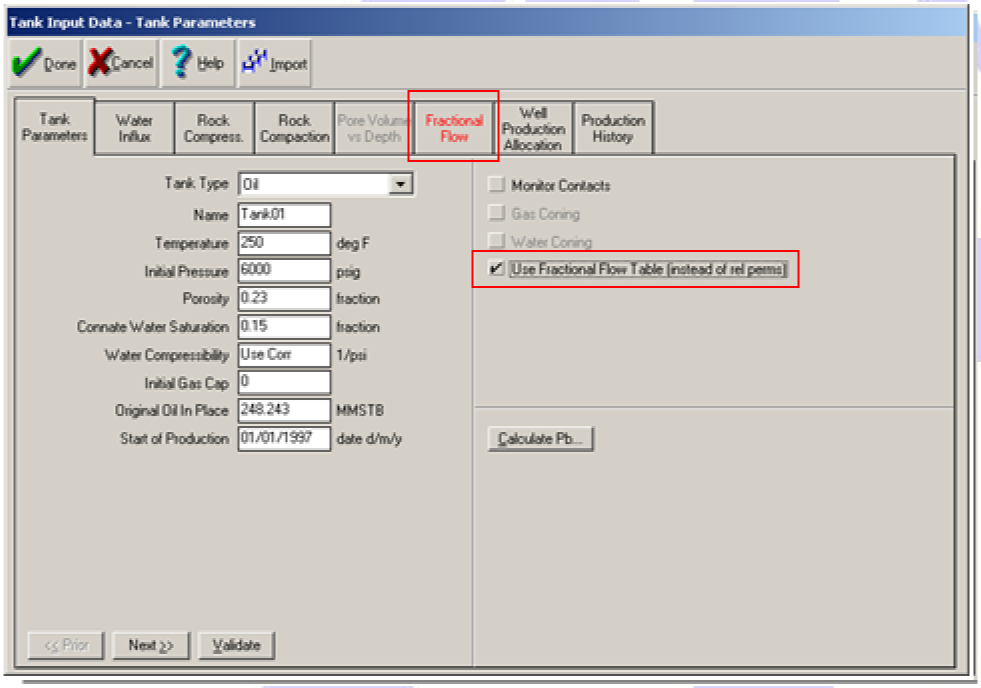
The calculation will automatically insert the residual saturation and maximum saturation into the table if they are not already specified in the input. Similarly the calculation will exclude calculation of any saturations below the residual saturation or any saturation above the maximum saturation.

2.4.4.2.6.3 Fractional Flow Tables

Fractional Flow Tables

If the calculations to determine the GOR, WC etc. are to be bypassed, fractional flow tables can be input. These tables define the predicted GOR, WC etc. with respect to; time, pressure and cumulative gas or oil rates.

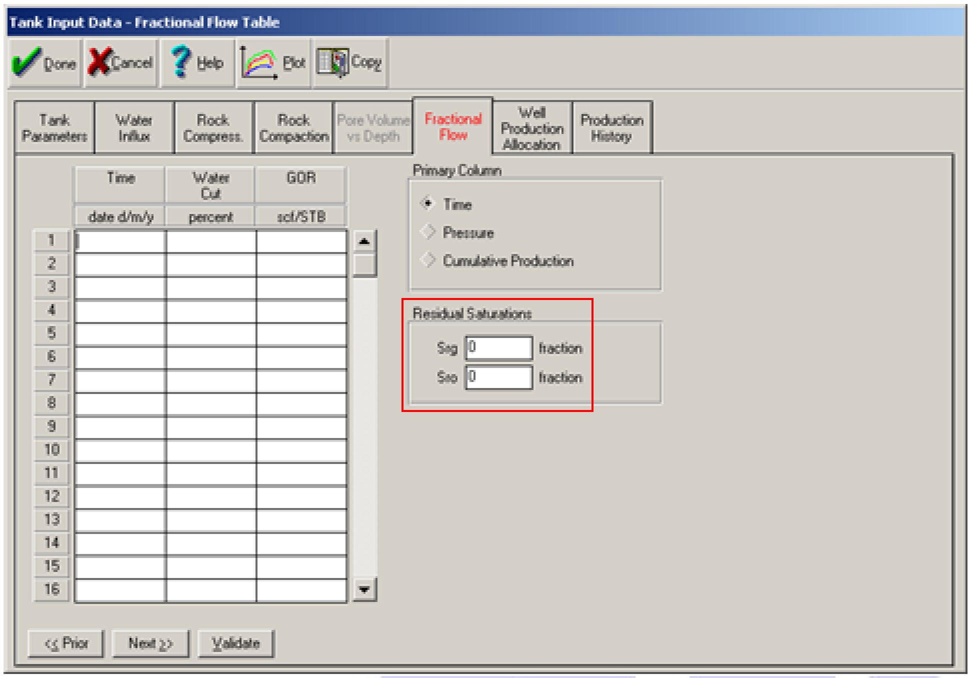
This option can be enabled from the main 'Tank Input' screen:


Tank Input Data - Tank Parameters
Done
Cancel
Help
Import
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Fractional Flow
Well Production Allocation
Production History
Calculate Pb...
<< Prior
Next >>
Validate

Tank Type: Oil
Name: Tank01
Temperature: 250 deg F
Initial Pressure: 6000 psig
Porosity: 0.23 fraction
Connate Water Saturation: 0.15 fraction
Water Compressibility: Use Corr 1/psi
Initial Gas Cap: 0
Original Oil In Place: 248.243 MMSTB
Start of Production: 01/01/1997 date d/m/y

☐ Monitor Contacts
☐ Gas Coning
☐ Water Coning
☑ Use Fractional Flow Table (instead of rel perms)

Selecting 'Use Fractional Flow Table (instead of rel perms)' will highlight the screen in which the tables may be entered:


Tank Input Data - Fractional Flow Table
Done
Cancel
Help
Plot
Copy
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Fractional Flow
Well Production Allocation
Production History
Time
Water Cut
GOR
date d/m/y
percent
scf/STB
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
<< Prior
Next >>
Validate

Primary Column
● Time
○ Pressure
○ Cumulative Production

Residual Saturations
Sgr 0 fraction
Sro 0 fraction

For an oil tank; water cut and GOR are required for which the primary column may be defined as; Time, Pressure or Cumulative Production.
The only other piece of information required in this screen are the residual saturations for oil and gas.

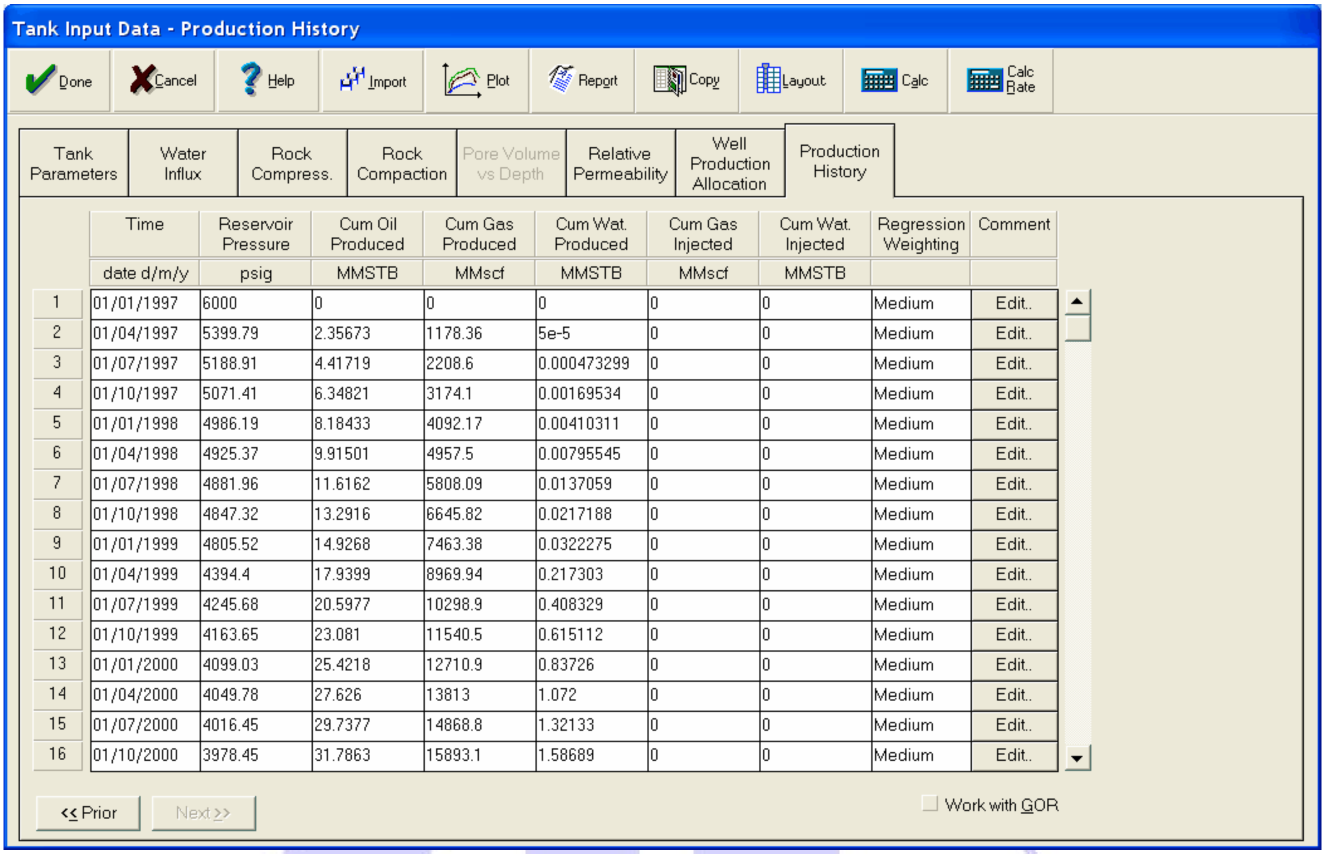
Having entered all of the necessary information, the prediction calculations will use these values when determining the predicted fluid behaviour.

It should be noted when using this method that the water cut values must represent the reality of the system. If they are too large, or too little, the predictions reliability will be diminished.

2.4.4.2.7 Entering the Tank Production History

To access the tank production history, choose **Input Tank Data** and select the 'Production History' tab.

If entry of 'Production History' has been set in the option dialogue to be ***by Well*** then it can also be calculated from the well production history and allocation data entered in the 'Well Data' section.


Tank Input Data - Production History
Done
Cancel
Help
Import
Plot
Report
Copy
Layout
Calc
Calc Rate
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Well Production Allocation
Production History
<< Prior
Next >>

	Time	Reservoir Pressure	Cum Oil Produced	Cum Gas Produced	Cum Wat. Produced	Cum Gas Injected	Cum Wat. Injected	Regression Weighting	Comment
	date d/m/y	psig	MMSTB	MMscf	MMSTB	MMscf	MMSTB		
1	01/01/1997	6000	0	0	0	0	0	Medium	Edit..
2	01/04/1997	5399.79	2.35673	1178.36	5e-5	0	0	Medium	Edit..
3	01/07/1997	5188.91	4.41719	2208.6	0.000473299	0	0	Medium	Edit..
4	01/10/1997	5071.41	6.34821	3174.1	0.00169534	0	0	Medium	Edit..
5	01/01/1998	4986.19	8.18433	4092.17	0.00410311	0	0	Medium	Edit..
6	01/04/1998	4925.37	9.91501	4957.5	0.00795545	0	0	Medium	Edit..
7	01/07/1998	4881.96	11.6162	5808.09	0.0137059	0	0	Medium	Edit..
8	01/10/1998	4847.32	13.2916	6645.82	0.0217188	0	0	Medium	Edit..
9	01/01/1999	4805.52	14.9268	7463.38	0.0322275	0	0	Medium	Edit..
10	01/04/1999	4394.4	17.9399	8969.94	0.217303	0	0	Medium	Edit..
11	01/07/1999	4245.68	20.5977	10298.9	0.408329	0	0	Medium	Edit..
12	01/10/1999	4163.65	23.081	11540.5	0.615112	0	0	Medium	Edit..
13	01/01/2000	4099.03	25.4218	12710.9	0.83726	0	0	Medium	Edit..
14	01/04/2000	4049.78	27.626	13813	1.072	0	0	Medium	Edit..
15	01/07/2000	4016.45	29.7377	14868.8	1.32133	0	0	Medium	Edit..
16	01/10/2000	3978.45	31.7863	15893.1	1.58689	0	0	Medium	Edit..

☐ Work with GOR

Entering the Tank Production History

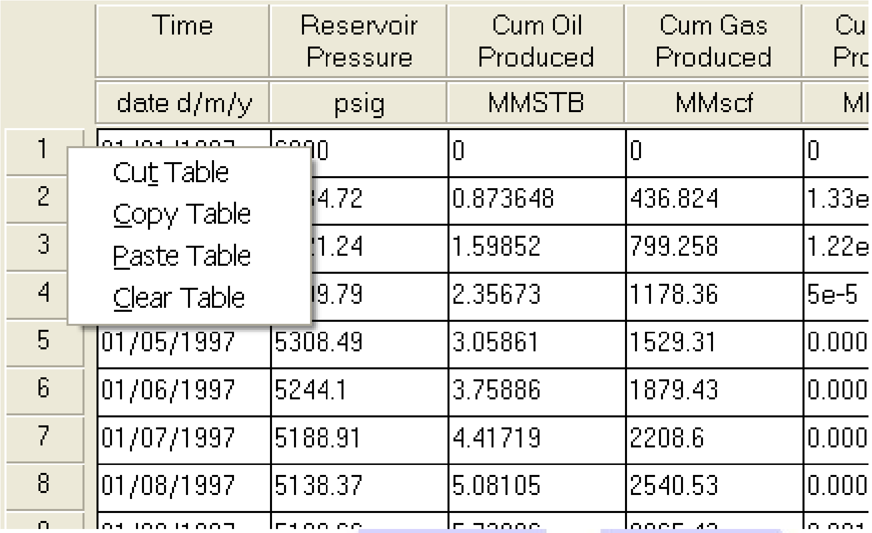
The data required are:

- **Time**
- **Reservoir Pressure**
- **Cumulative Oil Produced**
- **Cumulative Gas Produced**
- **Cumulative Water Produced**
- **Cumulative Gas Injected**
- **Cumulative Water Injected**

➡ **Some reservoir pressure fields can left be blank if no data are available. These points can optionally be included in the Graphical and Analytical Methods - in this case the pressure value will be interpolated.**

Be careful, this is not a substitute for good data!

➡ Pointing the mouse to number of any row and using the right click of the mouse will allow to access the editing options. Data can be exported/imported to the clipboard



	Time	Reservoir Pressure	Cum Oil Produced	Cum Gas Produced	Cu Pro
	date d/m/y	psig	MMSTB	MMscf	MI
1			0	0	0
2		4.72	0.873648	436.824	1.33e
3		1.24	1.59852	799.258	1.22e
4		9.79	2.35673	1178.36	5e-5
5	01/05/1997	5308.49	3.05861	1529.31	0.000
6	01/06/1997	5244.1	3.75886	1879.43	0.000
7	01/07/1997	5188.91	4.41719	2208.6	0.000
8	01/08/1997	5138.37	5.08105	2540.53	0.000

The production/injection, GOR and CGR entered must be cumulative. Note that Cumulative GOR = Cum Gas / Cum Oil.

See Table Data Entry for more information on entering the production history.

Input Fields

Work with GOR	(**Oil and Gas condensate Tanks Only**) Check this box if the cumulative GOR instead of the gas cumulative production is to be entered. When the GOR is supplied, the program automatically calculates the gas cumulative production
Work with CGR	(**GAS Tanks Only**) Check this box if the cumulative CGR is a preferred value to the condensate cumulative production. When the CGR is input, the program automatically calculates the condensate cumulative production

Please note that the regression weighting refers to the weighting placed by the regression engine when automatic history matching is performed. This entry will be ignored if no automatic history matching is done. The default is always medium for all points.

Some reservoir pressure fields can left be blank if no data are available. These points can optionally be included in the Graphical and Analytical Methods - in this case the pressure value will be interpolated.

Command Buttons

Calc	Calculates the tank production history rate and pressure. Active only for 'By Well' production history entries only. See Calculating Tank Production History 209 for more details
Calc Rate	Calculates the tank production history rate only. Active only for 'By Well' production history entries only
Plot	Displays the different production / injection, GOR and CGR data points versus time. Click on 'Variable' to select another data column to plot
Report	Allows creation of reports of production history data
Import	This option is used to import production data from an external file. Note that if any production data exists for the current well, the user will be asked if it is desired to replace the existing data or append to the existing data. This file can either be: • An ASCII file in which the user must specify a filter to define the columns in the file and how they translate to the MBal data columns. • A Petroleum Expert's *.HIS history file. • An ODBC data source. • A Production Analyst (*.REP) file. This file can contain production data for a number of tanks. MBal will search for the tank name in the file that matches the currently selected tank - if it finds one then it will import the production data for that tank

➡ **The 'Calc' and 'Calc Rate' buttons are not available if the variable PVT model has been selected. This is because we cannot calculate the consolidated pressure without knowing which wells are producing from which PVT layer - and we do not know the PVT layer depths over time until we have done a full material balance.**

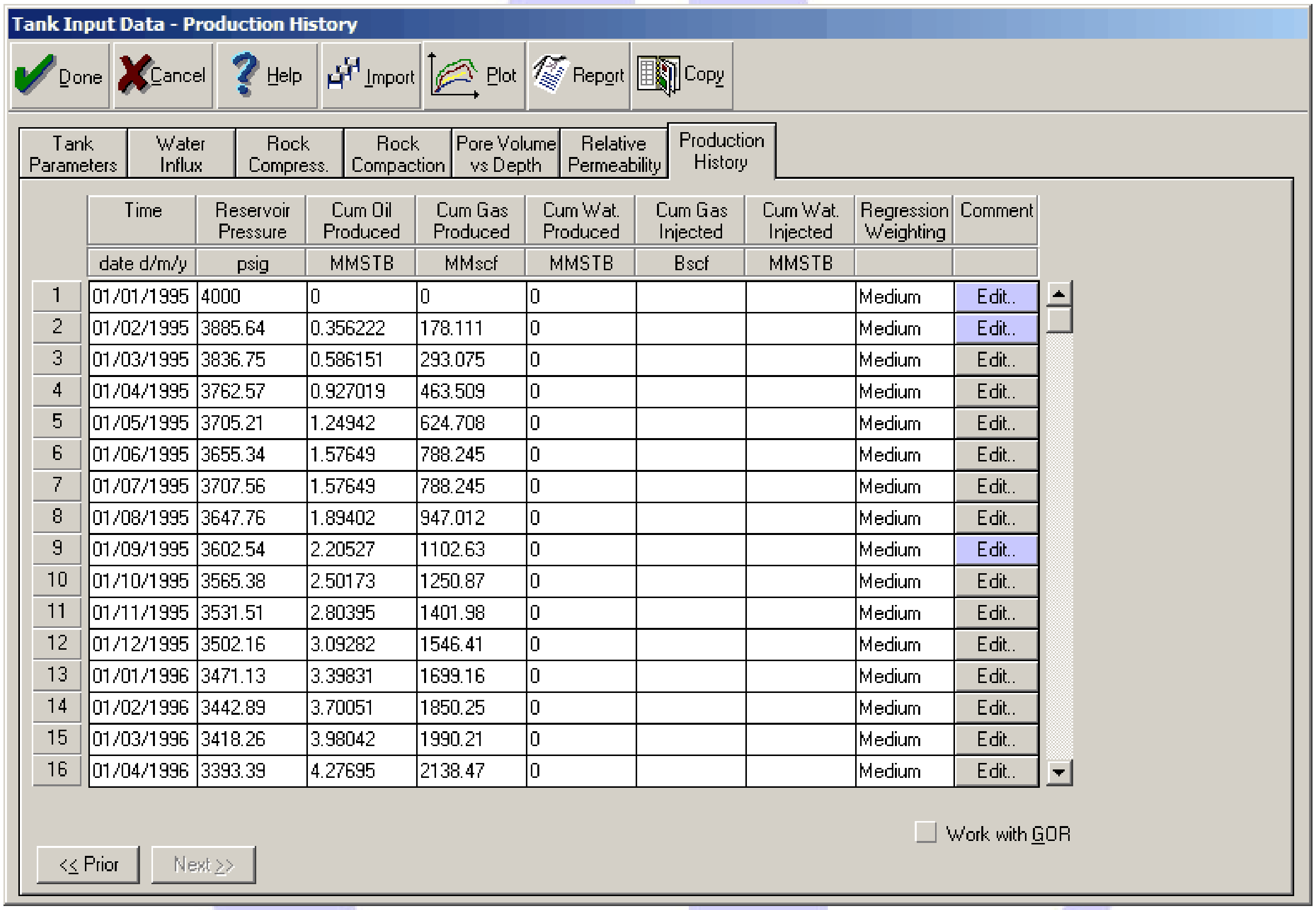
Further options

Switch points on/off	If the objective is to set the status of a particular data point to 'off', then this can be done by clicking on the serial number of the data point (from the 'production history' tab). The selected point will then be greyed out to indicate its status set to 'off.' These points will not be considered in the history matching process
Validate	To know the reason for the 'production history' tab being red, the '**Validate**' option can be used at the bottom of the screen. For the stated case, it is indeed the result of two points on the same date
Weighting	The regression weighting of the points can be adjusted from the drop down menu box on the right of the screen as shown in the figure below. The regression weighting will help to decide the importance of a particular point during the history matching process. for e.g. the last data point which might

	have a very strong confidence in the measurement, can be set to a higher weighting. On the other hand, a data point where the measurement has low accuracy, can be set as 'low'

2.4.4.2.7.1 Production History Comment

The comments tab in the production history table allow the user to enter information that the user feels are relevant for each point. If one of the tabs contains comments, then the colour will change as shown below:


Tank Input Data - Production History
Done
Cancel
Help
Import
Plot
Report
Copy
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
☐ Work with GOR
<< Prior
Next >>

	Time	Reservoir Pressure	Cum Oil Produced	Cum Gas Produced	Cum Wat. Produced	Cum Gas Injected	Cum Wat. Injected	Regression Weighting	Comment
	date d/m/y	psig	MMSTB	MMscf	MMSTB	Bscf	MMSTB		
1	01/01/1995	4000	0	0	0			Medium	Edit..
2	01/02/1995	3885.64	0.356222	178.111	0			Medium	Edit..
3	01/03/1995	3836.75	0.586151	293.075	0			Medium	Edit..
4	01/04/1995	3762.57	0.927019	463.509	0			Medium	Edit..
5	01/05/1995	3705.21	1.24942	624.708	0			Medium	Edit..
6	01/06/1995	3655.34	1.57649	788.245	0			Medium	Edit..
7	01/07/1995	3707.56	1.57649	788.245	0			Medium	Edit..
8	01/08/1995	3647.76	1.89402	947.012	0			Medium	Edit..
9	01/09/1995	3602.54	2.20527	1102.63	0			Medium	Edit..
10	01/10/1995	3565.38	2.50173	1250.87	0			Medium	Edit..
11	01/11/1995	3531.51	2.80395	1401.98	0			Medium	Edit..
12	01/12/1995	3502.16	3.09282	1546.41	0			Medium	Edit..
13	01/01/1996	3471.13	3.39831	1699.16	0			Medium	Edit..
14	01/02/1996	3442.89	3.70051	1850.25	0			Medium	Edit..
15	01/03/1996	3418.26	3.98042	1990.21	0			Medium	Edit..
16	01/04/1996	3393.39	4.27695	2138.47	0			Medium	Edit..

Anybody picking up the file has the ability to quickly identify which comment screens have information in them based purely on the colour of the button.

2.4.4.2.7.2 Production History layout

Originally, production history was always entered with cumulative rates up to a defined date. In the **new IPM Version 7**, historical data can now be entered as a cumulative per month or per year.

Select the type of method of entering cumulative rates.

Cumulative to date	This is the default method that has always been used in previous versions of the program. The cumulative rate entered for a particular date is the volume produced/injected up to that date
Cumulative per month	If your data is in the form of cumulative volumes produced each month then use this option. In this case it is not clear when the associated pressure is measured e.g. first day of the month, last day of the month etc. So you will also need to select on which day of the month the pressure is measured
Cumulative per year	If your data is in the form of cumulative volumes produced each year then use this option. In this case it is not clear when the associated pressure is measured e.g. first day of the year, last day of the year etc. So you will also need to select on which day of the year the pressure is measured

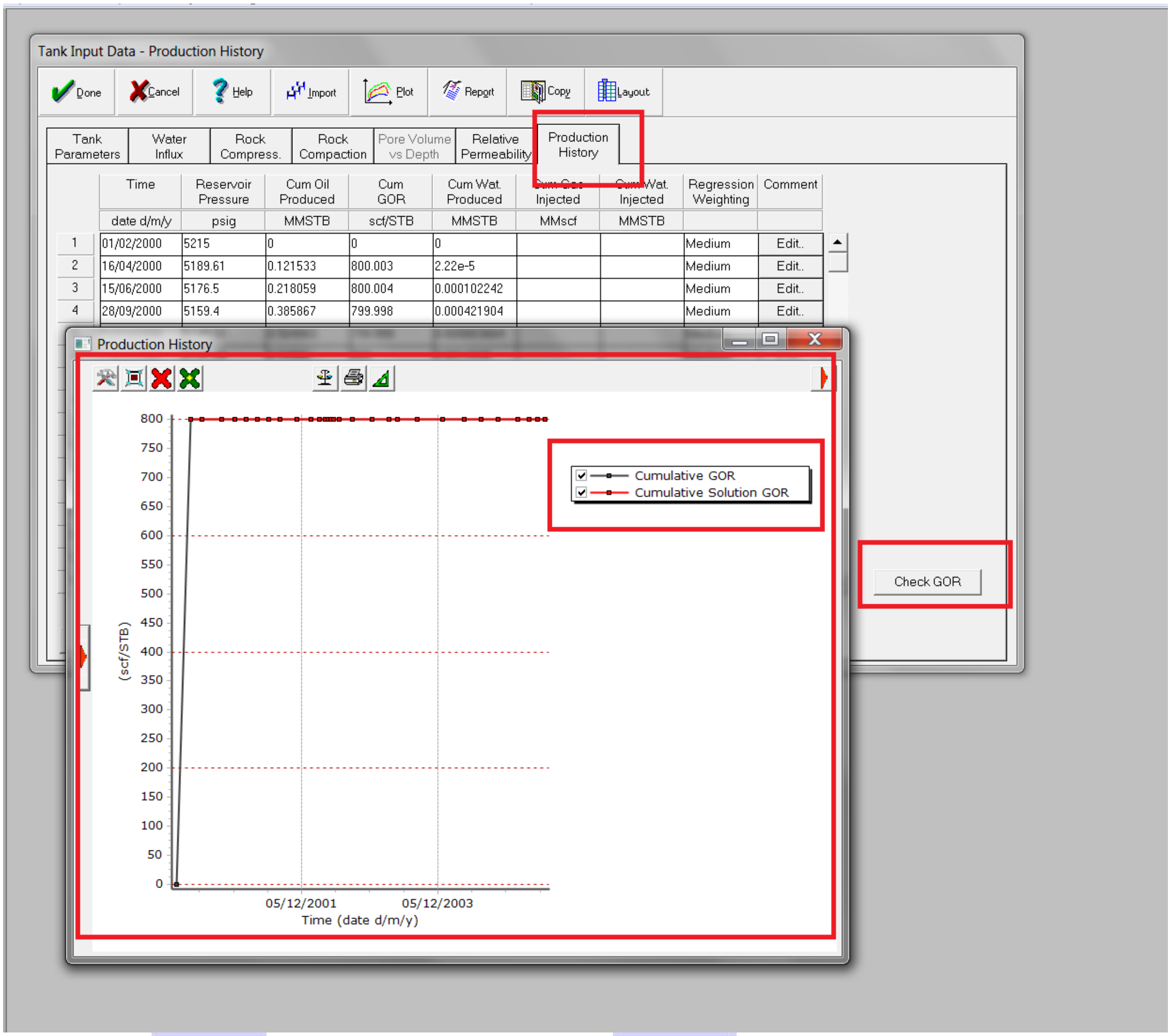
If you change the selection after production history has already been entered in another format, **MBAL** will convert that data to the new format.

2.4.4.2.8 Production History

This tab is used to enter the pressure and cumulative production/injection history of the tank. It can also be calculated from the well production and allocation data entered in the 'Well Data' section using the 'Production Allocation' table described below.

New in IPM 8.0

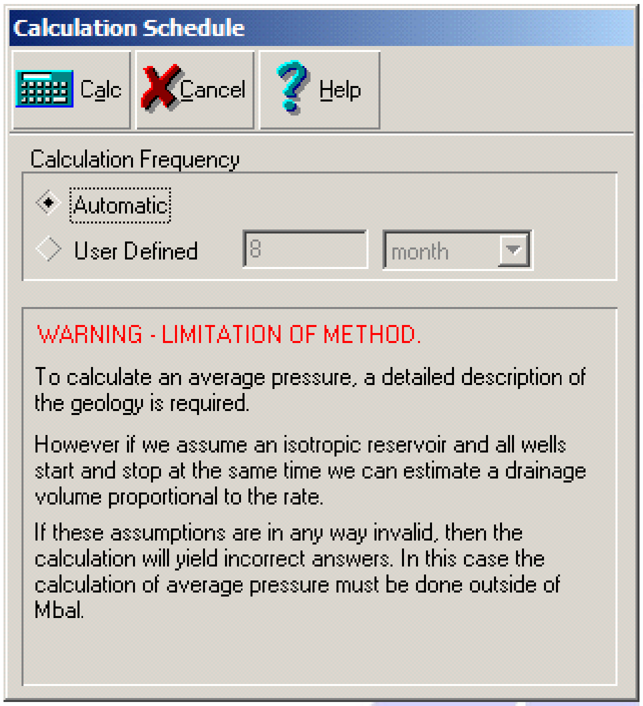
The Check GOR button in the history data allows the user to compare the (i) solution GOR from the PVT and (ii) production history. This allows a quality check of the input data used. (see screen below)


Tank Input Data - Production History
Done
Cancel
Help
Import
Plot
Report
Copy
Layout
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
Check GOR
Production History
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
(scf/STB)
05/12/2001
05/12/2003
Time (date d/m/y)
☑ Cumulative GOR
☑ Cumulative Solution GOR

	Time	Reservoir Pressure	Cum Oil Produced	Cum GOR	Cum Wat. Produced	Cum Gas Injected	Cum Wat. Injected	Regression Weighting	Comment
	date d/m/y	psig	MMSTB	scf/STB	MMSTB	MMscf	MMSTB		
1	01/02/2000	5215	0	0	0			Medium	Edit..
2	16/04/2000	5189.61	0.121533	800.003	2.22e-5			Medium	Edit..
3	15/06/2000	5176.5	0.218059	800.004	0.000102242			Medium	Edit..
4	28/09/2000	5159.4	0.385867	799.998	0.000421904			Medium	Edit..

2.4.4.2.9 Calculating the Tank Production History and Pressure

Clicking **Calc** will consolidate the different well production tables entered in the 'Well Data Production History' tabs.



Calculation Frequency

● Automatic

○ User Defined 8 month

WARNING - LIMITATION OF METHOD.

To calculate an average pressure, a detailed description of the geology is required.

However if we assume an isotropic reservoir and all wells start and stop at the same time we can estimate a drainage volume proportional to the rate.

If these assumptions are in any way invalid, then the calculation will yield incorrect answers. In this case the calculation of average pressure must be done outside of Mbal.

The program will combine the input tables using the 'allocation factor' defined for each well. After the calculations, the old production history table will be destroyed and the new calculated one will be displayed.

At each time step, the cumulative productions are consolidated by adding the cumulative production/injection of each well corrected for its allocation factor. Refer to Well Data-Production History 179 above for the definition of the allocation factor.

To calculate an average pressure, a detailed description of the geology is required. However if we assume an isotropic reservoir and all the wells start and stop at the same time, we can estimate a drainage volume proportional to the rate. The average tank pressure is calculated from the static pressure of each well assuming that:

$$\bar{p} = \frac{\sum_i p_i \cdot V_i}{\sum_i V_i}$$

ref: L.P. Dake: The Practice of Reservoir Engineering, Elsevier, section 3.3, p80.

The V_i is calculated from production history and PVT evaluated at the current reservoir pressure.

➡ **If these assumptions are in any way invalid, then the calculation will yield incorrect answers. In this case the calculations must be done outside of MBAL or with the Reservoir Allocation tool in MBAL**

Input Fields

Calculation	This parameter defines when an average tank pressure and cumulative

Frequency	productions / injections are calculated.	
	Automatic	The program performs a calculation every 3 mon
	User Defined	The user can defined any date increment in days months or years in the adjacent fields

Command Buttons

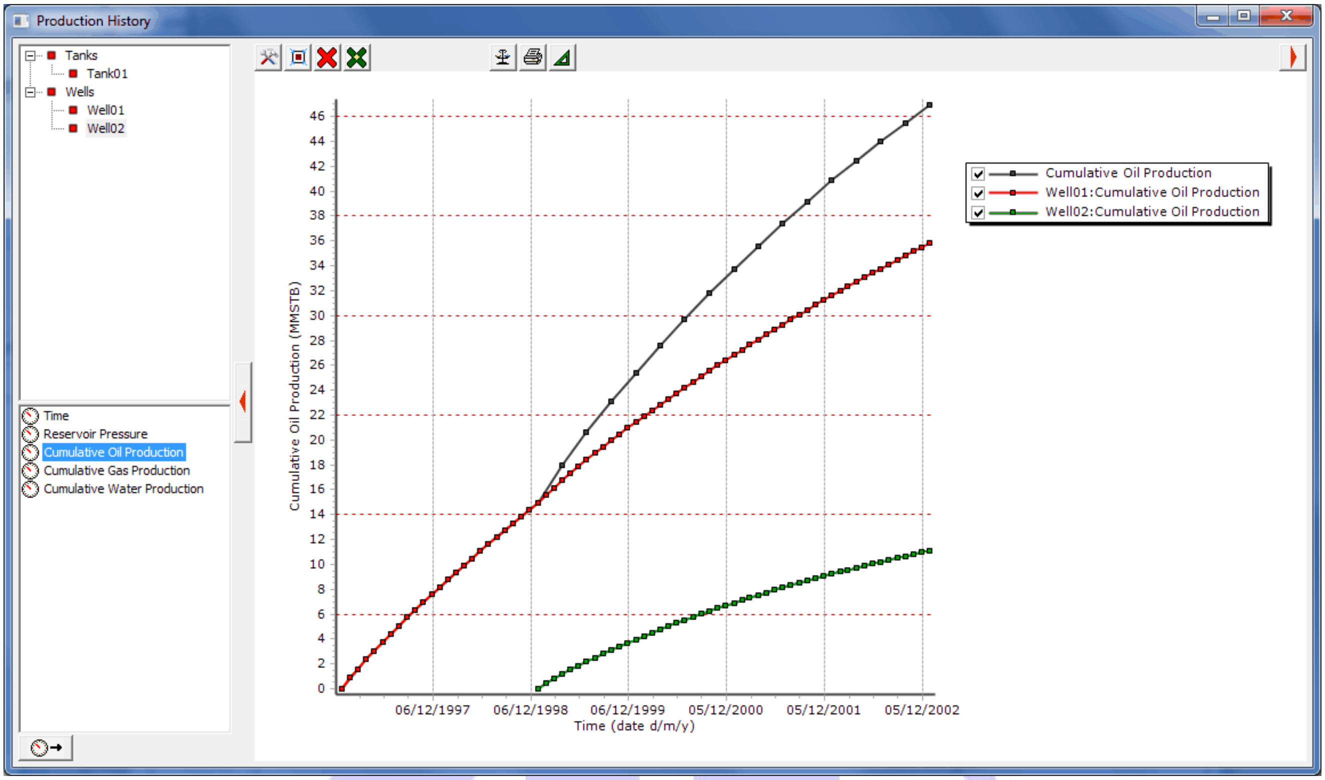
Calc	Performs the production consolidation and average reservoir pressure calculation

2.4.4.2.10 Calculating the Tank Production History Rate Only

Clicking **Calc Rate** will consolidate the different well production tables entered in the 'Well Data Production History' tabs. There are two differences between the 'Calc' button and the 'Calc Rate'. Firstly, it does not calculate the tank pressures. Secondly it does not delete the existing tank production history table but uses the existing times and pressure at which to recalculate the rates. The purpose of two buttons is to allow different well allocations to be used when calculating pressures and rates.

2.4.4.2.11 Plotting Tank Production History

Clicking **Plot** displays the production data from the different wells in the model.

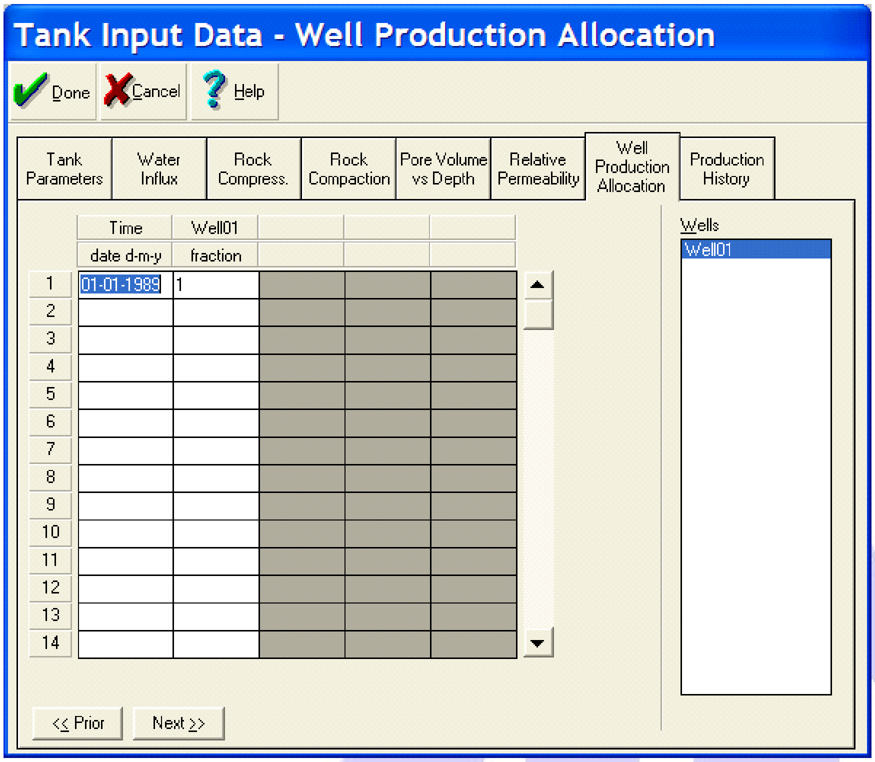

Production History
Tanks
Tank01
Wells
Well01
Well02
Time
Reservoir Pressure
Cumulative Oil Production
Cumulative Gas Production
Cumulative Water Production
Cumulative Oil Production (MMSTB)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
06/12/1997
06/12/1998
06/12/1999
05/12/2000
05/12/2001
05/12/2002
Time (date d/m/y)
Cumulative Oil Production
Well01:Cumulative Oil Production
Well02:Cumulative Oil Production

2.4.4.2.12 Production Allocation

This tab simply shows a different view of the data entered in the **Production Allocation** data page in the **Wells Data** dialogue.

In the **Wells Data** dialogue each table shown is per well - each column in the table is for one of the tanks connected to the current well.

In this tab, each table shown is per tank - each column in the table is for one of the wells connected to the current tank.


Tank Input Data - Well Production Allocation
Done
Cancel
Help
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Well Production Allocation
Production History
Wells
<< Prior
Next >>

	Time	Well01
	date d-m-y	fraction
1	01-01-1989	1
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		

Wells: Well01

First select the producing wells

The Wells list shows which history wells are connected to the current tank. The wells can be connected or disconnected to the current tank by selecting or deselecting the well in the 'Wells' list. To connect a well, highlight the well in the 'Wells' list. The well will be added to the allocation table. To disconnect a well, de-select the well name in the list. This will remove the well from the table.

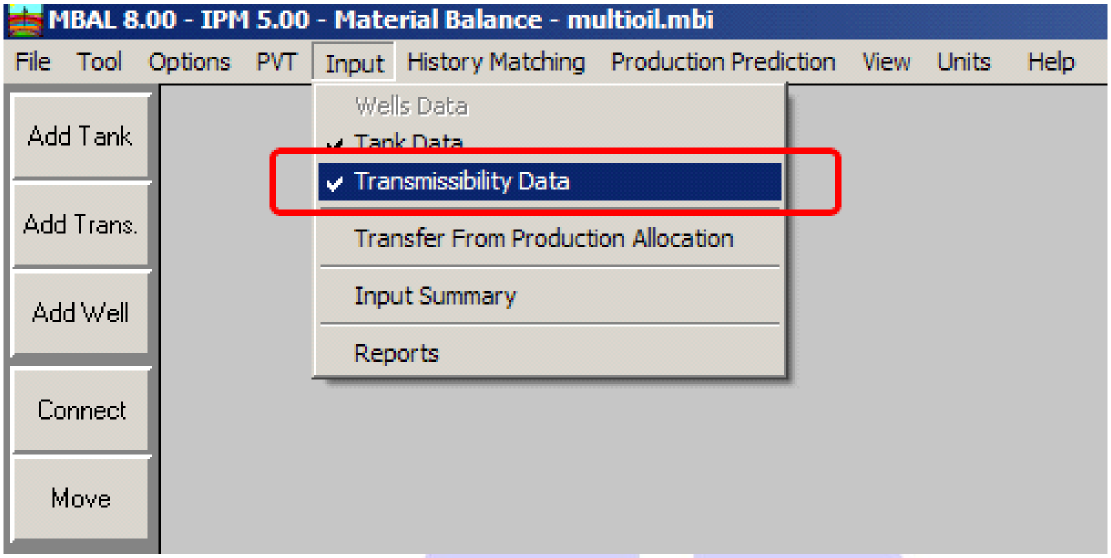
Next allocate a production fraction to each well

The allocation fraction is the fraction of the well production or injection history to be allocated to the tank. This allows the definition of the multiplying coefficient in use for this well, when the well histories are consolidated.
Any value between 0 and 1 is valid. 1.0 allocates the complete well production /injection to the tank. 0.0 switches this well off completely.
(See 'Reservoir Production History'.)

If this fraction changes over time, more than one row can be entered in the table. Each row will define the time at which the allocation factor takes effect.

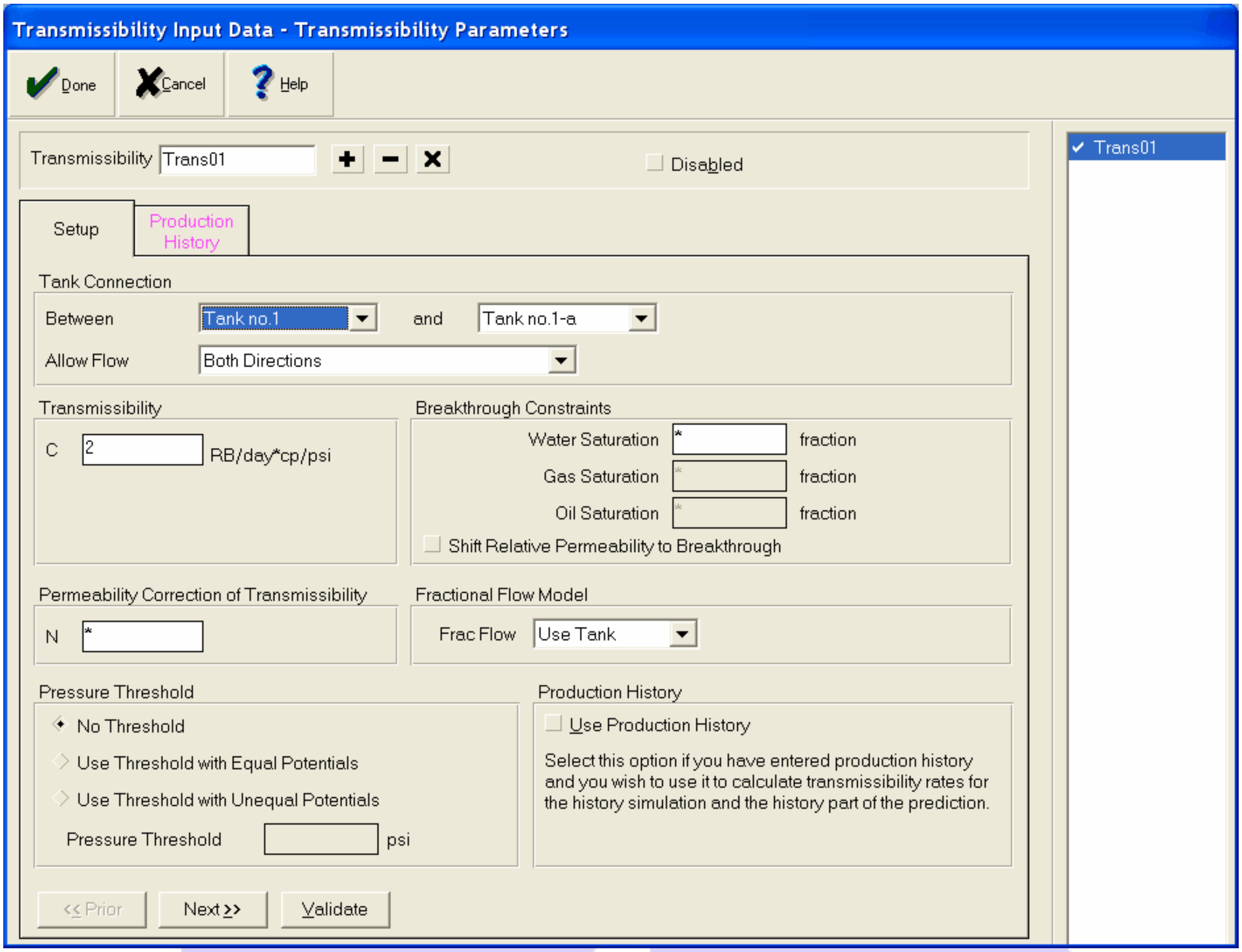
2.4.4.3 Transmissibility Data

This option is enabled only if the 'Multi Tanks' option is chosen in the 'Options' menu. The 'Transmissibility Parameter's dialogue box described in the following section is used to establish the different communication links between tanks.


MBAL 8.00 - IPM 5.00 - Material Balance - multioil.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Wells Data
Tank Data
Transmissibility Data
Transfer From Production Allocation
Input Summary
Reports
Add Tank
Add Trans.
Add Well
Connect
Move

2.4.4.3.1 Transmissibility Parameters

To access the 'Transmissibility Parameters' tab, choose 'Input Transmissibility Data' and select the 'Setup' tab:



Transmissibility: Trans01

☐ Disabled

Tank Connection

Between: Tank no.1 and Tank no.1-a

Allow Flow: Both Directions

Transmissibility

C: 2 RB/day*cp/psi

Breakthrough Constraints

Water Saturation: * fraction

Gas Saturation: * fraction

Oil Saturation: * fraction

☐ Shift Relative Permeability to Breakthrough

Permeability Correction of Transmissibility

N: *

Fractional Flow Model

Frac Flow: Use Tank

Pressure Threshold

● No Threshold

○ Use Threshold with Equal Potentials

○ Use Threshold with Unequal Potentials

Pressure Threshold: psi

Production History

☐ Use Production History

Select this option if you have entered production history and you wish to use it to calculate transmissibility rates for the history simulation and the history part of the prediction.

Select transmissibility from the list to the right of the dialogue in use. Data sheets containing invalid information for the connection selected will automatically be highlighted RED. Data sheets containing missing but not invalid data will be highlighted MAGENTA. This is only a warning. Press **Validate** to run the validation procedure and pinpoint any possible errors.

Input Fields

Tank Connection	Defines the tanks connected through this transmissibility. Two tanks must be specified. The connection between the tanks can also be created on the main plot (see Manipulating Object section above)
Allow Flow	This can setup the transmissibility to allow flow to occur in either direction or in one direction only. If the desired effect is to model flow in only one direction, then this can be defined in the user preferred direction
Transmissibility	This parameter defines the transmissibility between the tanks. The transmissibility model implemented in **MBAL** is the following.

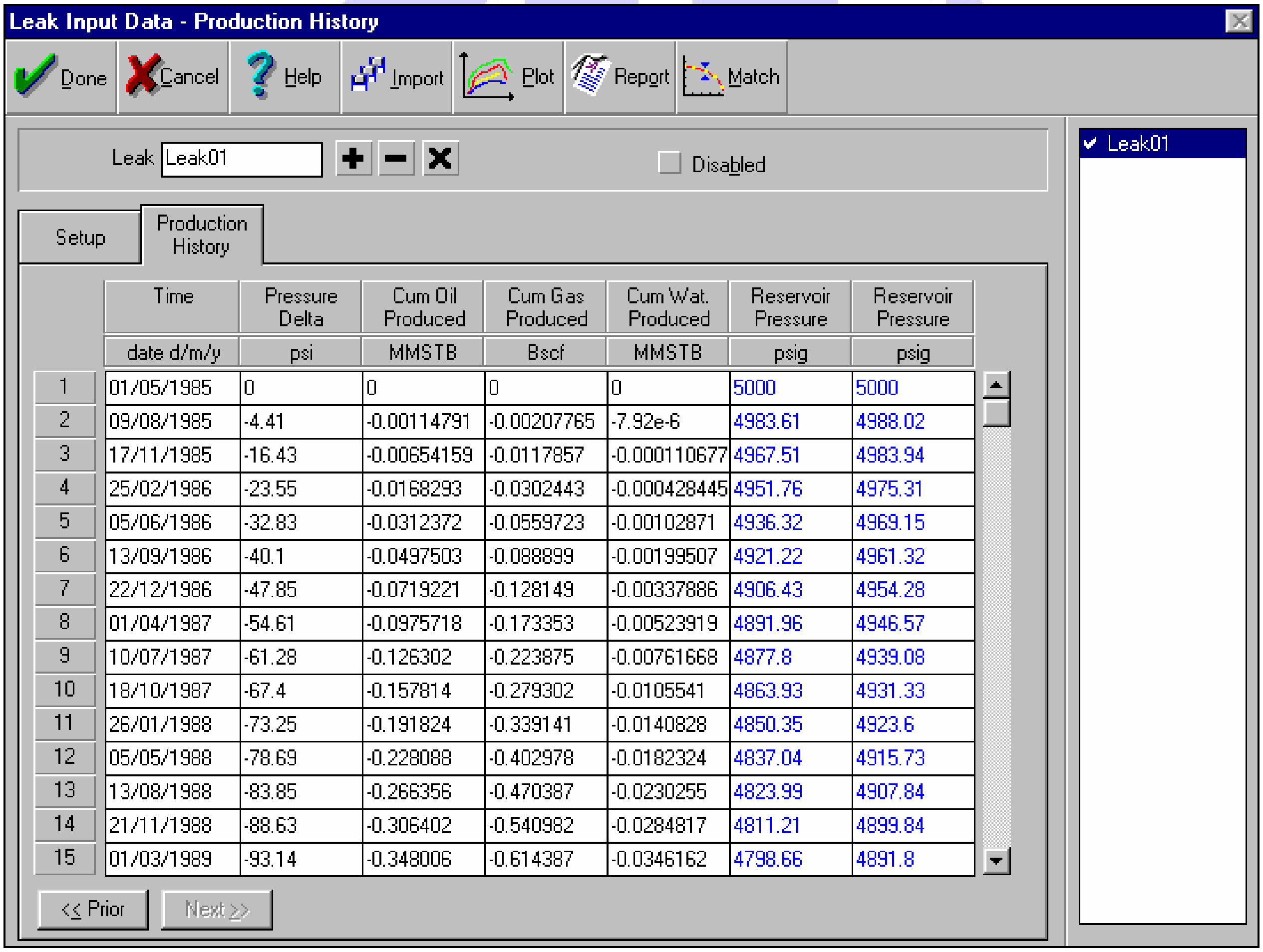
	$Q_t = C * \sum_i \frac{Kr_i}{\mu_i} * \Delta P$ where: Q_t is the total downhole flow rate, C is the transmissibility constant, Kr_i is the relative permeability of phase i, μ_i is the viscosity of phase i, ΔP is the pressure difference between the two tanks. Q_t is then split into Q_o, Q_g and Q_w using the relative permeability curves. If relative permeability curves have been entered for the transmissibility, the total flowrate will relate to those defined values. Otherwise the relative permeability curves for the producing tank will be used. Certain phases can be prevented from flow by using the 'Breakthrough Constraints' described below. The relative permeability curves can be corrected to maintain their shape while starting from the breakthrough saturation.
Permeability Correction of Transmissibility	This factor can be used to correct the transmissibility for changing permeability in the tank as the pressure decreases. The formula used is: $k = k_i\left(1.0 + C_f\left(P - P_i\right)\right)^N$ Where N is the entered value. The permeability decrease is proportional to the ratio of the current pore volume to the initial pore volume raised to a power.
Breakthrough Constraints	In an attempt to account for the geometry of the reservoir; one or two phases can be prevented from flowing until the corresponding phase saturation reaches a pre-set value. If no breakthrough constraints are required, enter an asterisk in these fields (‘*’). If a value is entered, it will tell the program that the relevant phase will not flow until the saturation in the upstream tank reaches this value. When the saturation reaches the breakthrough value, the relative permeability will jump from zero to the value at the breakthrough saturation. If a smooth profile is desired, the *Shift Relative Permeability to Breakthrough* option should be selected. This will shift the relative permeability curve starting point to the breakthrough saturation while maintaining the shape of the original curve
Rel Perms	Used to select which set of relative permeability’s should be used. If *Use Tank* is selected then the relative permeabilities are taken from the tank from which the fluid is flowing. If *Use Own* is selected then the user must click **'Edit'** and enter a set of relative permeabilities specifically for the transmissibility

<table>
<tr>
<td>Pressure Threshold</td>
<td>Three options are available:
<table>
<tr><td>No Threshold</td><td>Tanks which are joined by transmissibilities are assumed to have equal potentials. In other words there is no flow between tanks when they are at their initial pressures. If the two tanks have different pressures, it is assumed that this was caused by the tanks being at different depths and the pressure difference is purely due to hydrostatic effects. As a simulation or prediction progresses and the tank pressures change from their initial values, MBAL always subtracts the initial pressure difference to remove the effect of hydrostatic pressure differences.
A transmissibility is defined to allow flow between tanks as soon as the pressure difference deviates from the initial pressure difference. In other words the transmissibility does not require a significant pressure difference before it allows fluid to flow</td></tr>
<tr><td>Use Threshold with Equal Potentials</td><td>This option allows the user to specify a pressure threshold. As the prediction or simulation progresses, MBAL checks if the pressure difference across the transmissibility is above the threshold pressure. If it is not, the transmissibility is modelled without allowing flow between the tanks. As soon as the pressure difference increases to above the threshold pressure, the transmissibility is assumed to have started to flow and we model it as for '<i>No Threshold</i>' above. Three important points:
Once the pressure difference increases above the threshold and the transmissibility starts to flow, it will never close again for a particular simulation/prediction. This is true even if the pressure difference drops below the threshold pressure.
MBAL assumes that the pressure threshold works in both directions so it always checks the absolute pressure difference being above the pressure threshold.
Once the transmissibility has started to flow we do all transmissibility calculations on the normal pressure difference i.e. we do not subtract the pressure threshold.
Note that for this case, MBAL still obeys the rule that tanks are initially at equal potentials. So any pressure difference is always the current pressure difference minus the original pressure difference</td></tr>
<tr><td>Use Threshold with Unequal</td><td>This option is exactly the same as the ‘<i>Use Threshold with Equal Potentials</i>’ except for the following difference:
MBAL now assumes that the initial pressure difference in the tanks was not due to hydrostatic differences but due an</td></tr>
</table>
</td>
</tr>
</table>

<table>
<tr><td></td><td><table><tr><td>Potentials</td><td>actual potential difference which was supported by the pressure threshold in the transmissibility.
This means that any pressure difference calculated is simply the difference between the current tank pressures and it does NOT subtract the initial pressure difference</td></tr></table></td></tr>
<tr><td>Use Production History</td><td>If need be, flow rates between tank can be obtained from a look-up rather than computed using the above equation. To do so check the <i>From History</i> check box and fill in the <i>Production History</i> tab described below. The transmissibility production history will then be used for a history simulation and any history simulation at the beginning of the production prediction. It can also be used to calculate an equivalent transmissibility which can be used in prediction. This option can be useful if the fluxes between the tanks have been calculated in a reservoir simulator</td></tr>
</table>

2.4.4.3.2 Transmissibility Production History

To access the 'Transmissibilities Production History' tab, choose Input|Transmissibility Data and select the 'Production History' tab.



Leak: Leak01

☐ Disabled

✔ Leak01

	Time	Pressure Delta	Cum Oil Produced	Cum Gas Produced	Cum Wat. Produced	Reservoir Pressure	Reservoir Pressure
	date d/m/y	psi	MMSTB	Bscf	MMSTB	psig	psig
1	01/05/1985	0	0	0	0	5000	5000
2	09/08/1985	-4.41	-0.00114791	-0.00207765	-7.92e-6	4983.61	4988.02
3	17/11/1985	-16.43	-0.00654159	-0.0117857	-0.000110677	4967.51	4983.94
4	25/02/1986	-23.55	-0.0168293	-0.0302443	-0.000428445	4951.76	4975.31
5	05/06/1986	-32.83	-0.0312372	-0.0559723	-0.00102871	4936.32	4969.15
6	13/09/1986	-40.1	-0.0497503	-0.088899	-0.00199507	4921.22	4961.32
7	22/12/1986	-47.85	-0.0719221	-0.128149	-0.00337886	4906.43	4954.28
8	01/04/1987	-54.61	-0.0975718	-0.173353	-0.00523919	4891.96	4946.57
9	10/07/1987	-61.28	-0.126302	-0.223875	-0.00761668	4877.8	4939.08
10	18/10/1987	-67.4	-0.157814	-0.279302	-0.0105541	4863.93	4931.33
11	26/01/1988	-73.25	-0.191824	-0.339141	-0.0140828	4850.35	4923.6
12	05/05/1988	-78.69	-0.228088	-0.402978	-0.0182324	4837.04	4915.73
13	13/08/1988	-83.85	-0.266356	-0.470387	-0.0230255	4823.99	4907.84
14	21/11/1988	-88.63	-0.306402	-0.540982	-0.0284817	4811.21	4899.84
15	01/03/1989	-93.14	-0.348006	-0.614387	-0.0346162	4798.66	4891.8

If the fluxes between the tanks are known, for example from a reservoir simulation run, they can be entered in this screen. This data may be used in two different places:

1. If the ‘Use Production History’ check box is checked on the 'Transmissibility Parameter' screen, the program will use this table as a lookup table to estimate the fluxes between tanks rather than using the correlation. This can be used in a history simulation and also in the history simulation part of a prediction.
2. This data can be used to calculate an equivalent transmissibility. The matching is performed after the **MBAL** history simulation run.

Select a transmissibility from the list to the right of the dialogue in use. Enter the time and cumulative rates. Although the table has columns for 'Delta Pressure' and the pressure of the two adjoining tanks, these values are calculated internally by ***MBAL,*** hence the reason for not entering anything in these columns. When this screen is re-entered, the columns will automatically be updated.

Command Buttons

Match	This option allows a transmissibility equivalent to be calculated with respect to the production history. As inputs it uses the production history, the relative permeability curves of the producing tank and the PVT. See 'Transmissibility Matching' below for more information
Import	This option is used to import production data from an external file. Note that if any production data exists for the current tank, the user will be asked if the existing data is to be replaced or it is to be appended to the existing data. This file can either be: An ASCII file, in which a filter needs to be specified to define the columns in the file and how they translate to the MBal data columns. A Petroleum Expert's *.HIS history file. An ODBC data source
Plot	This option allows a plot of the production history entered for this transmissibility to be viewed
Report	This option allows a listing of the production history data to be produced
Match	This option allows a transmissibility equivalent to the production history to be calculated. As inputs it uses the production history, the relative permeability curves of the producing tank and the PVT. See Transmissibility Matching for more information

2.4.4.3.3 Transmissibility Matching

This plot can be used to calculate 'C' by matching on production history for that transmissibility. Note that only transmissibility production history can be used which is usually available from reservoir simulators.

The transmissibility can be matched on a transmissibility-by-transmissibility basis. The following steps must be performed before matching can take place:

- Enter the PVT.
- Enter the relative permeability curves. Either enter curves for the transmissibility in the 'Setup' tab or enter the rel perm curves for both tanks connected to the transmissibility.
- Enter a set of production history points in the 'Transmissibility Data' dialogue.

For each point in the transmissibility production history data, **MBAL** plots the total downhole rate versus the delta pressure between the two tanks. It also calculates the total mobility for each point. If the **Regression** menu item is clicked on, **MBAL** calculates the transmissibility factor (C) which best matches the data. This is done by minimising the error in the basic transmissibility equation:

$$Q_{tot} = C\Delta P\left(\frac{k_{ro}}{\mu_o} + \frac{k_{rw}}{\mu_w} + \frac{k_{rg}}{\mu_g}\right)$$

In this process, the total rate and delta pressure can be calculated from the production history. However the relative permeabilities are more complex. They are defined as follows:

- Calculate the Fw/Fg/Fo from the production history
- Fw/Fg/Fo can also be expressed as a ratio of relative permeabilities eg.

$$F_w = \frac{\dfrac{k_{rw}}{\mu_w}}{\dfrac{k_{rw}}{\mu w} + \dfrac{k_{ro}}{\mu_o}}$$

- Since relative permeabilities for different phases have opposite trends, there is always a unique saturation for which such a ratio has a particular value, and thus a unique set of Kr values.

If the weighting on a data point is to be altered, double click the point to display the **Match Point Status** dialogue. To set the weighting for a group of points at once, select a range of data points whilst holding down the right mouse button. The **Match Point Status** dialogue will be displayed on releasing the mouse button and the new setting will be assigned to all the points within the area selected.

➡ **This method of transmissibility matching does not work if breakthroughs on fluid contact depths have been used.**

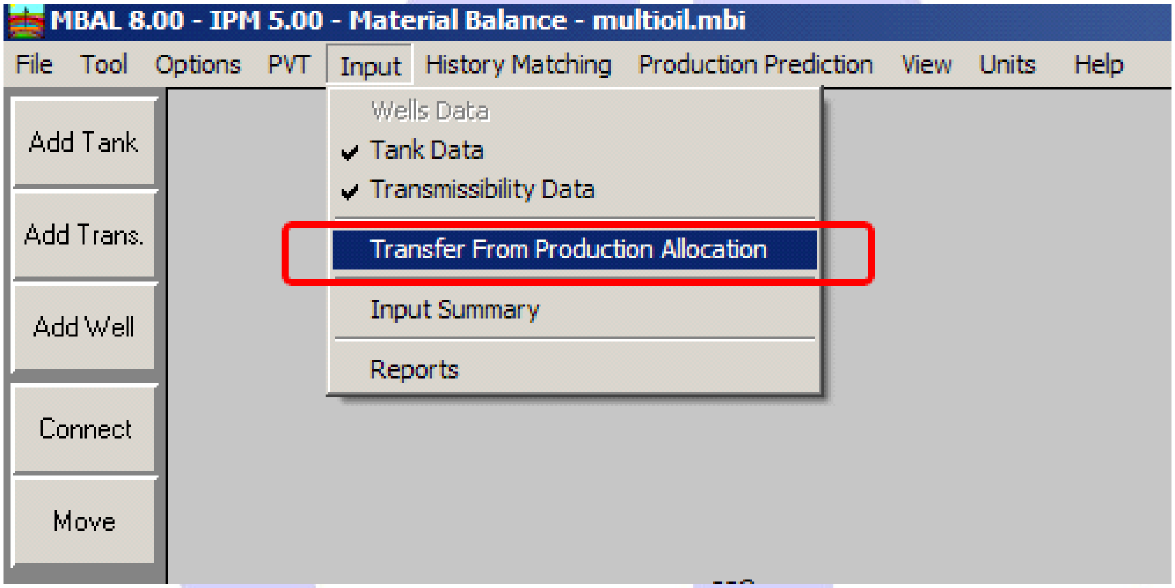
Menu Commands

Transmissibility	Select the transmissibility name for the production history data points which are to be plotted
Previous Transmissibility	Select the previous transmissibility in the list

Next Transmissibility	Select the next transmissibility in the list
Regression	Perform the regression to calculate C. This can be either done on the currently selected transmissibility or all transmissibilities at once
Sampling	If there is a large number of points, this can be used to select ten equally spaced points by rate or delta pressure. It can also be used to enable or disable all points
Save	Use this option to save the last calculated C for the currently displayed transmissibility to the input data

2.4.4.4 Transfer from Reservoir Allocation

If an initial analysis was done with the 'Reservoir Allocation' tool in MBAL, the model and results can be directly transferred to the 'Material Balance' tool. This avoids re-entering the same data for the reservoir models and the wells in the system.


MBAL 8.00 - IPM 5.00 - Material Balance - multioil.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Wells Data
Tank Data
Transmissibility Data
Transfer From Production Allocation
Input Summary
Reports
Add Tank
Add Trans.
Add Well
Connect
Move

For details on the reservoir allocation tool, please refer to the chapter dedicated to this tool in the manual (Production Allocation 179).

2.4.4.5 Input Summary

This menu option displays the results table of the validation procedure.
The table indicates each object entered in the data set by name, any invalid data or information is highlighted. For easy identification, data sheets containing errors are highlighted in RED. Data sheets highlighted in MAGENTA are empty but not invalid, this is only a warning.

2.4.4.6 Input Reports

A report of the input menu parameters can be generated, once the relevant data has been supplied. Reports can be printed to include all the information entered so far, or printed to include only specific categories of data.

To print a report select **Input | Report** or click **Report** in the relevant dialogue box. Select the categories of data to print by checking the box to the left of the entry. The selected categories are retained in memory and reprinted each time a report is generated.

Categories between brackets, (e.g. PVT) indicate further report levels can be selected. To access these, double-click the category name.

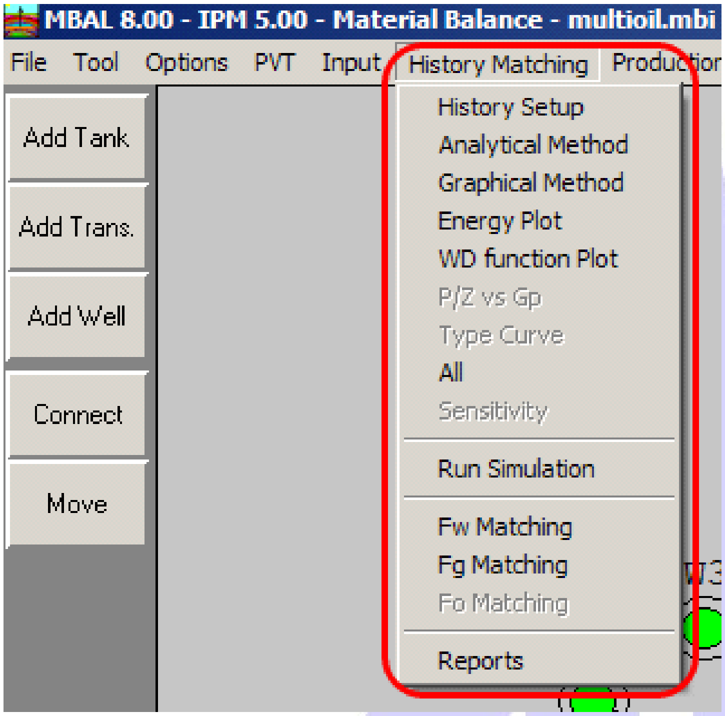
The following levels of Input data are accessible:

General Information	Includes the tool options as well as User Information and Comments entered in the **Options** menu
PVT	See PVT reports for information
Input Data	Includes the General Information, PVT, Well, Tank and Transmissibility Data report categories
Well Data	Includes the Well Parameters data and Well Model input data
Tank Data	Includes reservoir information entered in the 'Tank Parameters' dialogue box
Transmissibility Data	Includes the tank communication links data entered in the 'Transmissibilities Parameters' dialogue box
Aquifer Parameters	Includes the aquifer information entered in the 'Water Influx' dialogue box
Production History	Includes the reservoir pressure and production history information entered in the 'Reservoir Production History' and where applicable the 'Reservoir Pressure' and 'Production Well by Well' dialogue boxes
Production Simulation	Includes results of the production simulation run to determine the reservoir pressure and water influx

See Reports for information on selecting the report output and format.

2.4.5 History Matching

The following sections describe the **MBAL** program 'History Matching' menu.


MBAL 8.00 - IPM 5.00 - Material Balance - multioil.mbi
File
Tool
Options
PVT
Input
History Matching
Production
History Setup
Analytical Method
Graphical Method
Energy Plot
WD function Plot
P/Z vs Gp
Type Curve
All
Sensitivity
Run Simulation
Fw Matching
Fg Matching
Fo Matching
Reports
Add Tank
Add Trans.
Add Well
Connect
Move
W3

Overview

MBAL provides four separate plots to determine the reservoir and aquifer parameters:

- Graphical Method 236
- Analytical Method 226
- Energy Plot 243
- Dimensionless Aquifer Function (WD) Plot 244

All four plots can be displayed individually or simultaneously:

Individually	To view one plot, select the appropriate plot option from the History Matching menu
Simultaneously	To view all of the plots, select the All option from the History Matching menu

The 'Dimensionless Aquifer Function' plot is only available if an aquifer model has been activated in the model.

If the abnormally pressured gas reservoir option is used, **MBAL** provides two different plots:

- **P/Z Graphical Method**
- **Type Curve Plot**

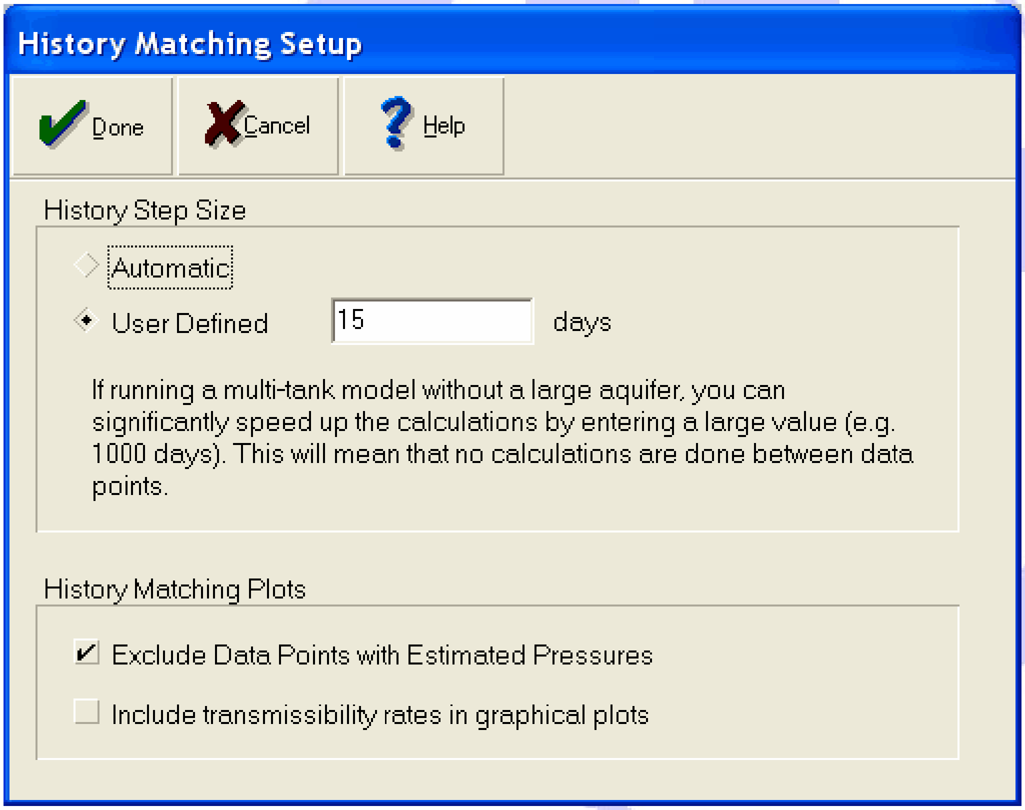
Simultaneous Plot Display

When more than one plot is displayed at a time, the following applies:

1. Only one plot is active at a time, i.e. has the input focus. This plot will normally have a blue title bar whereas the inactive plots will have a grey title bar.
2. The menu bar always displays the enabled options of the current active plot. The menu options vary between plots.
3. Clicking on an inactive plot, will make it active. New menu bar options will be displayed to reflect the current active plot.
4. By default all plots (active and inactive) are synchronised. That is, any change to the reservoir or aquifer properties will automatically be reflected on all plots.
5. Plots can be de-synchronised by choosing the **Windows Synchronize Plots** menu from the display menu. De-synchronising plots can be useful when the calculations are too slow (due to the number of data points for example), and the updating of all plots is taking too long. If this case, only the current active plot needs to be updated. When the calculations are finished, simply clicking an inactive plot will refresh / update it.
6. Plots may be tiled or cascaded for an alternate display arrangement.

2.4.5.1 History Setup

This dialogue is used to define various general inputs for the history matching section of the material balance tool:



History Step Size

○ Automatic

● User Defined 15 days

If running a multi-tank model without a large aquifer, you can significantly speed up the calculations by entering a large value (e.g. 1000 days). This will mean that no calculations are done between data points.

History Matching Plots

☑ Exclude Data Points with Estimated Pressures

☐ Include transmissibility rates in graphical plots

Input data

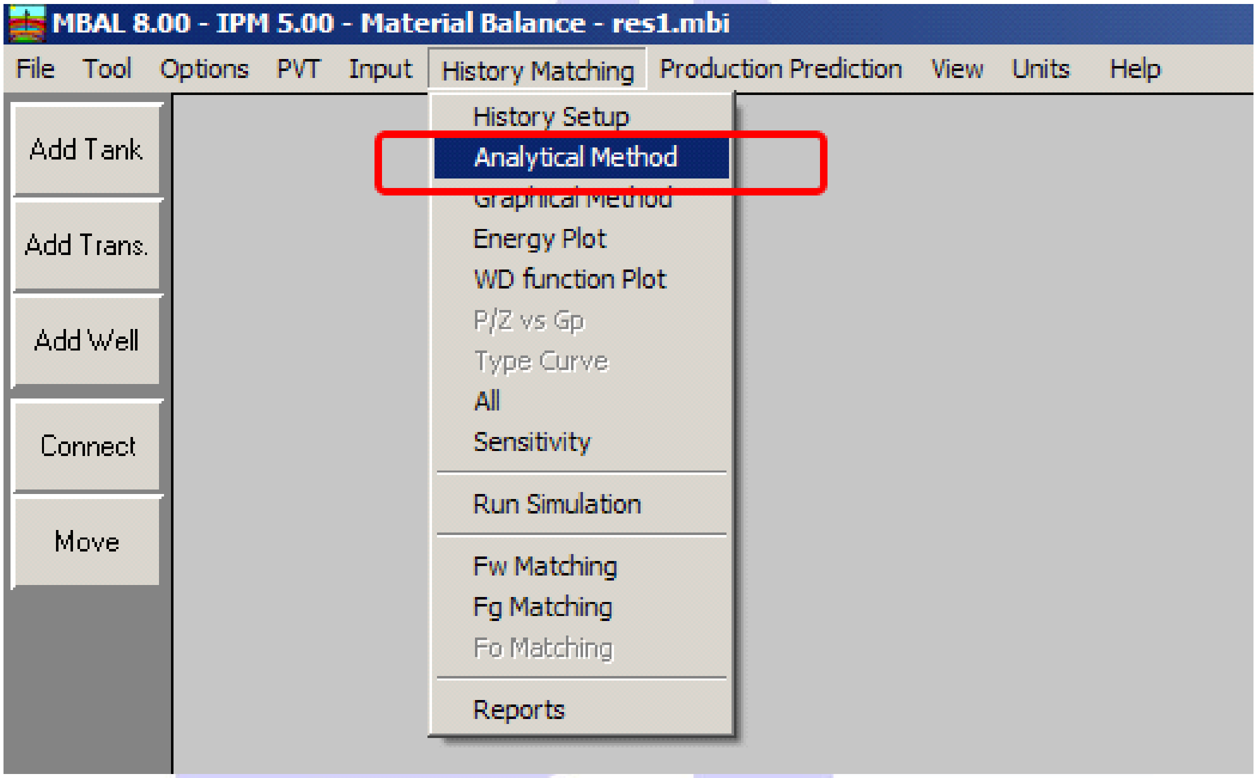
<table>
<tr>
<td>History Step Size</td>
<td colspan="2">During a history matching calculation, MBAL will always perform simulation calculations at each production history point to be included in the calculation. However, it may also perform calculations at intermediate steps to ensure that aquifer responses are correctly modelled. This is particularly important if production history data points are far apart. The history step size controls these intermediate steps.
If the automatic option is selected, MBAL will perform calculation steps at least every 15 days (more often if production history points occur more frequently). If the 'User Defined' method is selected, then the calculation step is controlled by the user.
If a multi-tank model is being run, it will be apparent that these calculations are slower compared to single tank models. This is due to the extra calculations required for the transmissibility. If no strong aquifers exist in the model, the calculations can be significantly speeded by increasing the calculation step size. In fact if a very large number is entered (e.g. 1000 days) the calculations will only be done at the times of the production history data points.
This step size applies to calculation of all the history matching plots, the analytic regression and the history simulation.

➡ If particularly strong aquifers are present or the variable PVT model is in use, using large time steps can lead to inaccurate results. In these cases, it is recommended that the impact of large time steps on should be verified results before using them consistently</td>
</tr>
<tr>
<td>History Matching Plots</td>
<td>Exclude Data Points with Estimated Pressures</td>
<td>This option allows the user to exclude any history production data points that have no pressure values and normally have the pressure value estimated by MBAL.
If this option is selected then the estimated points are excluded from all display and calculations. If the estimated points are to be included in the calculations then the following rules apply:
In the plot display the estimated pressure points will be used as if they were measured points. Also for multi-tank cases; the estimated points will also be accounted for in the initial history simulation when calculating the transmissibility rates.
In the analytical plot regression, the rules are somewhat different; as the pressures are estimated, they are not included in the regression. However for the multi-tank option we still use the estimated points in the history simulations that are run every iteration (we only use the rates for the history simulation anyway) - but they are still not included in the actual regression algorithm</td>
</tr>
<tr>
<td></td>
<td>Include transmissibility rates in graphical plots</td>
<td>This option allows adding the transmissibility rates to the various rates (e.g. F, Qg) displayed on the graphical plots. Note that the leak rates are always added to the analytic plot</td>
</tr>
</table>

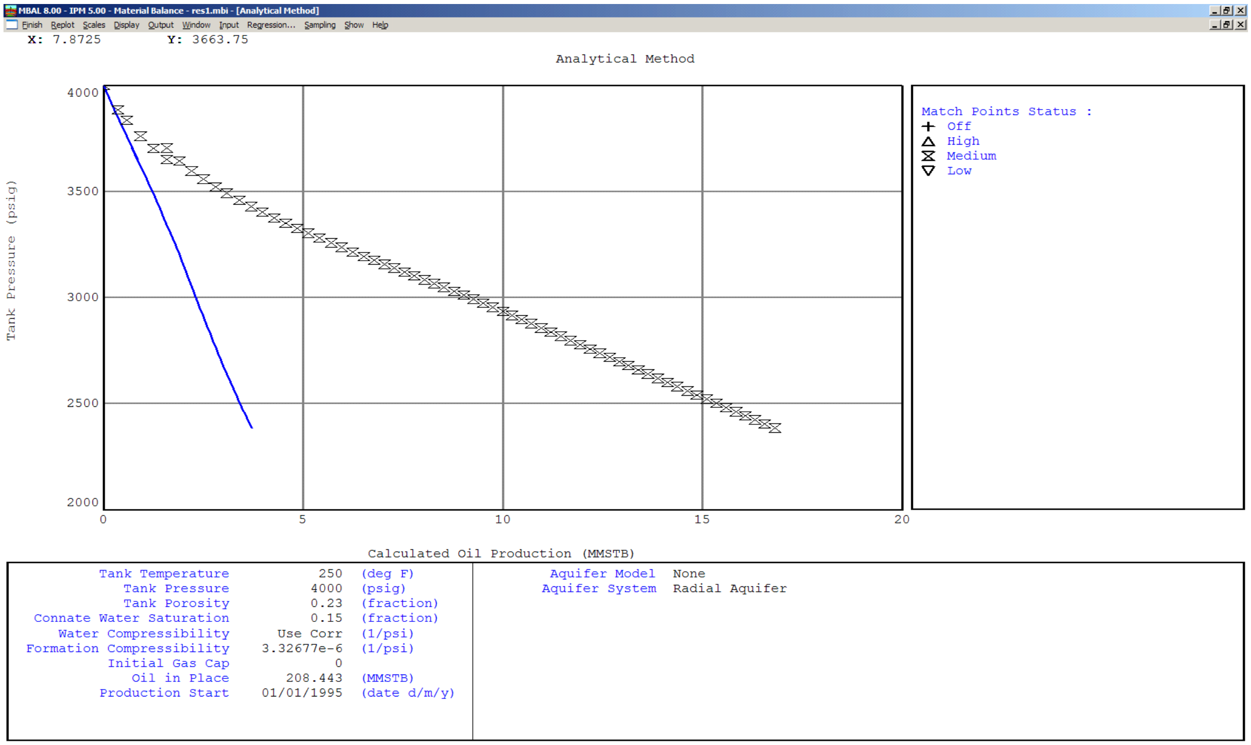
2.4.5.2 Analytical Method

The analytical method uses a non-linear regression engine to assist in estimating the unknown reservoir and aquifer parameters. This method is plot based, i.e. the response of the model is plotted against historical data.

To access the analytical method plot, choose the **History Matching|Analytical Method** option.


MBAL 8.00 - IPM 5.00 - Material Balance - res1.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Add Tank
Add Trans.
Add Well
Connect
Move
History Setup
Analytical Method
Graphical Method
Energy Plot
WD function Plot
P/Z vs Gp
Type Curve
All
Sensitivity
Run Simulation
Fw Matching
Fg Matching
Fo Matching
Reports

The following is a typical analytical method plot:


MBAL 8.00 - IPM 5.00 - Material Balance - res1.mbi - [Analytical Method]
Finish Replot Scales Display Output Window Input Regression... Sampling Show Help
X: 7.8725 Y: 3663.75
Analytical Method
Tank Pressure (psig)
4000
3500
3000
2500
2000
0
5
10
15
20
Calculated Oil Production (MMSTB)
Match Points Status :
Off
High
Medium
Low

Tank Temperature	250	(deg F)
Tank Pressure	4000	(psig)
Tank Porosity	0.23	(fraction)
Connate Water Saturation	0.15	(fraction)
Water Compressibility	Use Corr	(1/psi)
Formation Compressibility	3.32677e-6	(1/psi)
Initial Gas Cap	0	
Oil in Place	208.443	(MMSTB)
Production Start	01/01/1995	(date d/m/y)

Aquifer Model None
Aquifer System Radial Aquifer

On this plot, the program calculates the production of primary fluid based on the tank pressure and the production of secondary fluids from the history entered. The calculation is carried out in this manner because the calculation time decreases considerably when determining the PVT at a defined pressure rather than trying to define the rate at its corresponding pressure– this is particularly important when carrying out a regression.

	Oil Reservoir	**Gas Reservoir**	**Condensate Reservoir**
Inputs	Tank Pressure Gas production Water production Gas injection Water injection	Tank Pressure Water production	Tank Pressure Condensate Production Water production Gas injection Water injection
Calculated Values	Oil production Water Influx	Gas Equivalent production Water Influx	Gas production Water Influx

The plot always displays at least one curve and the history data points. This curve is:

- The calculated cumulative production using the reservoir & aquifer parameters of the last regression (a solid line).

If the tank has an aquifer then a second curve will also be displayed. This curve is:

- The calculated cumulative production of the reservoir without aquifer (by default this is a blue line although the colour can be changed)

- **The red line (calculated production of the reservoir without aquifer) is plotted as a safeguard to ensure the validity of the PVT and other reservoir properties. This line should always under-estimate the production and should always be located on the left hand side of the historical data points. If it is not the case, check the PVT properties or tables.**

If using a multitank system, another curve will also be displayed. This curve is the calculated cumulative production of the reservoir with aquifer (if present) but without the effect of the transmissibilities (by default this is a red dotted line although the colour can be changed)

However for generalised material balance we do something different. We calculate the equivalent of a history simulation where the pressures are calculated for the input oil, gas and water rates. We then plot the calculated pressure and input pressure both versus the main phase cumulative production (i.e. cumulative oil for an oil tank and cumulative gas for a gas tank). Since we have to run a full simulation for each calculated line, we do not display the line without the effect of the aquifer or the transmissibilities.

The data displayed on the plot is for one tank at a time. If the plot for a different tank is required, use the **Tanks, Previous Tank** or **Next Tank** menu items.

- As described above, the analytic method attempts to match the calculated and the input main phase rate. The main phase rate is always plotted on the X-axis of the plot. Therefore if the validity of the match is to be verified, look at the error between the data points and the calculated line in the X direction (the horizontal error) rather than the error in the Y direction (the vertical error). However the generalised material balance is in use, then the pressure is calculated so in this case examine the vertical error

- To change this value, select the **History Matching | History Set up** menu. Change *the History Step Size* setting to *User Defined* and enter a large number e.g. 1000 days. This will cause the regression to only use the entered times for the calculations instead of using 15 day sub-steps. However it is inevitable that this will reduce the accuracy of the calculations particularly if there is a large aquifer or data points are far apart - so it is advised to go back to the smaller time steps once a reasonable estimate has been found

- If a model is incorrectly matched or the input data is incorrect, the calculated line can sometimes reverse in the X direction i.e. the cumulative main phase rate plotted on the X axis can start to decrease. For an explanation, let us consider an oil tank. If the entered gas rate or water rate is too high to maintain the entered pressure (even with a zero oil rate), the only solution for the calculation is to ‘inject’ oil into the tank to maintain that pressure. Therefore the cumulative oil will decrease and the curve will appear to reverse. This may indicate that the current estimates of the input tank and aquifer parameters are wrong or the input production history is incorrect

- **For a multi-tank model, the plot displays one tank at a time. Before plotting the data, MBAL first runs a history simulation with the current model to calculate the transmissibility rates. These rates are then added to/subtracted from the tank**

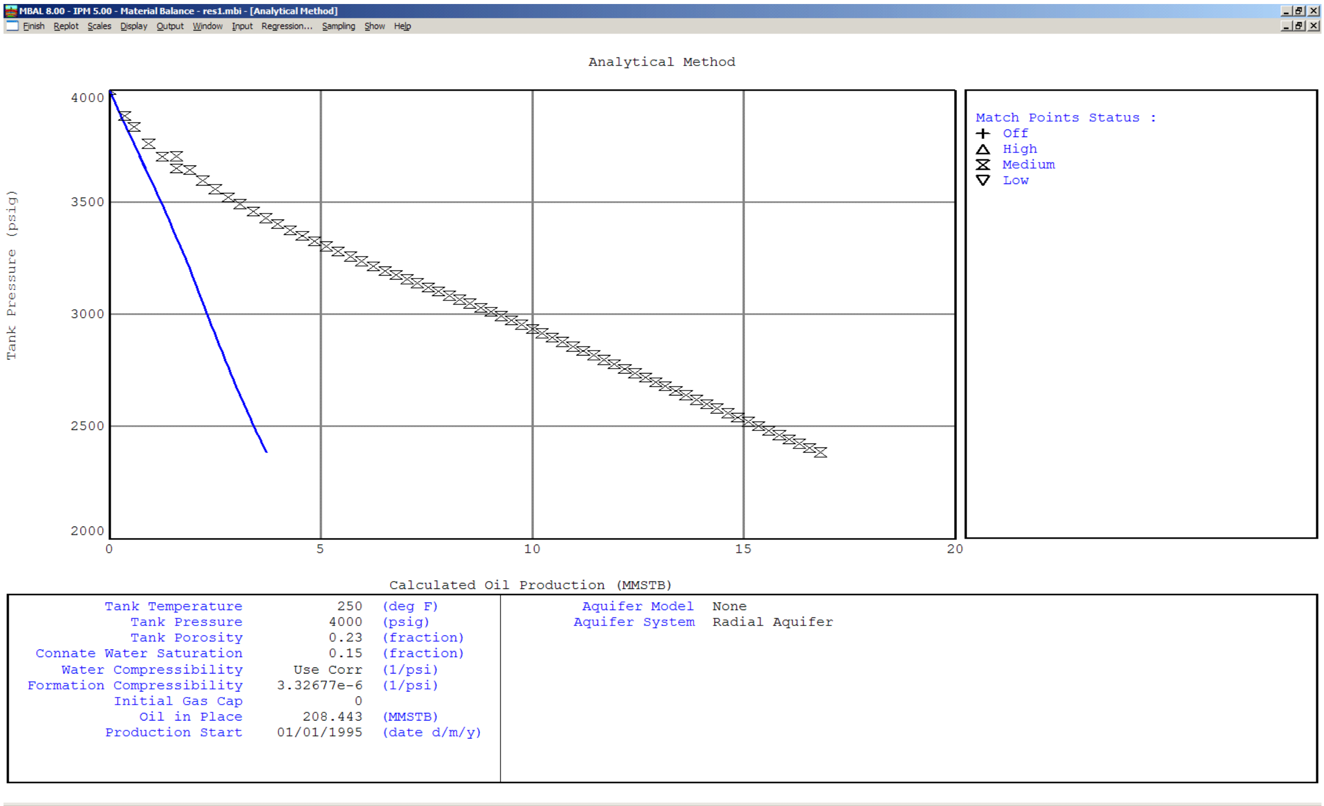
production history as if it was real production. The tank response can then be calculated as for a single tank model. Note however that during a regression the complete multi-tank model is calculated for each new estimate.

Menu Commands

<table>
<tr><td>Tanks</td><td colspan="2">Only for multi-tank option. The analytical plot only shows the response for one tank at a time. Use this menu to select the tank that is to be viewed. Similarly the Next and Previous menu items can be used to change the tank that is currently plotted</td></tr>
<tr><td>Input</td><td colspan="2">Accessing the standard tank and transmissibility edit dialogues allows the input data to be altered directly. If any data is changed, then for the single tank case the plot is recalculated immediately. As the multi-tank calculation can be very slow, we do not recalculate immediately - when the plots are to be recalculated to show any changes to the tank/transmissibility data, select the Calculate menu item</td></tr>
<tr><td>Regression</td><td colspan="2">Run the regression calculation</td></tr>
<tr><td rowspan="6">Sampling</td><td colspan="2">This menu contains various items for changing the data on which the plot and the regression work.</td></tr>
<tr><td>Enable All
Disable All</td><td>act on all points in the current tanks production history</td></tr>
<tr><td>Disable Estimated Points</td><td>will disable any points that do not have any pressure entered and therefore would normally have the pressure estimated</td></tr>
<tr><td>On Time,
On Reservoir Pressure and
On Production History</td><td>are used to automatically enable only 10 points in the production history. The sampling will be equally spaced on the quantity in the menu selected</td></tr>
<tr><td>Show Estimated Pressure Points</td><td>affects the display only. It is used switch on/off the display of points with no pressure value</td></tr>
<tr><td>Exclude Data Points with Estimated Pressures</td><td>is the same as described in the 'History Matching Setup' section</td></tr>
</table>

2.4.5.2.1 Regressing on Production History

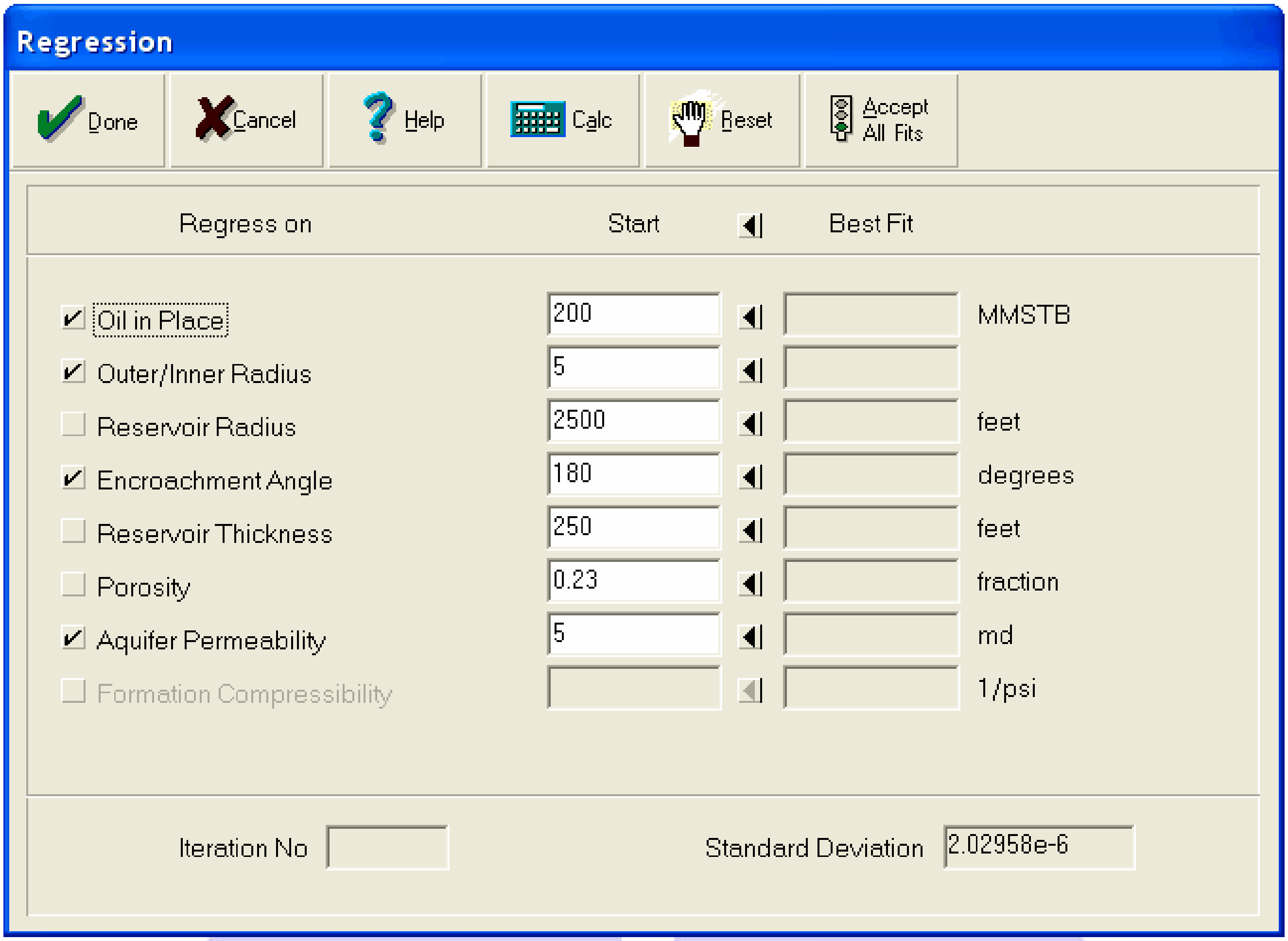
To access the 'Regression' dialogue box, click the Regression plot menu option. The content of this dialogue box depends on the: type of reservoir, aquifer selected, the existence of a gas cap, etc.


MBAL 8.00 - IPM 5.00 - Material Balance - res1.mbi - [Analytical Method]
Finish Replot Scales Display Output Window Input Regression... Sampling Show Help
Analytical Method
Tank Pressure (psig)
4000
3500
3000
2500
2000
0
5
10
15
20
Calculated Oil Production (MMSTB)
Match Points Status :
+ Off
△ High
Medium
▽ Low

Tank Temperature	250	(deg F)
Tank Pressure	4000	(psig)
Tank Porosity	0.23	(fraction)
Connate Water Saturation	0.15	(fraction)
Water Compressibility	Use Corr	(1/psi)
Formation Compressibility	3.32677e-6	(1/psi)
Initial Gas Cap	0	
Oil in Place	208.443	(MMSTB)
Production Start	01/01/1995	(date d/m/y)

Aquifer Model	None
Aquifer System	Radial Aquifer

When this option is selected, the following screen will appear, allowing selection of parameters to regress on and to perform the regression:



Regress on	Start	Best Fit	
☑ Oil in Place	200		MMSTB
☑ Outer/Inner Radius	5		
☐ Reservoir Radius	2500		feet
☑ Encroachment Angle	180		degrees
☐ Reservoir Thickness	250		feet
☐ Porosity	0.23		fraction
☑ Aquifer Permeability	5		md
☐ Formation Compressibility			1/psi

Iteration No

Standard Deviation 2.02958e-6

Running a Regression:

1. Select the parameters to be regressed. For single tank cases, this is done by selecting the tick box to the left of the parameters. For multi-tank cases, click on the *Yes/No* button to the left of the *Start* column. If all of the unselected parameters are to be removed from the regression dialogue, press the **Filter** button - press it again to display them again.
2. Click **Calc.** The program regresses on the **So + Sg + Sw = 1** equation. After a few iterations (maximum 500) the program will stop, and display in the right hand column the set of parameters giving the best mathematical fit.

   Please note that the 'best mathematical fit' may not necessarily be the best solution. Some of the parameters may seem probable, while others may not.
3. The regression can be stopped at any time by clicking the **Abort** command button. The program will display the best set of parameters found up to that point in the right hand column

For single tanks, the standard deviation shows the error on the material balance

equation re-written
(F - We) / (N*E) - 1 = 0 for oil reservoirs
(F - We) / (G*E) - 1 = 0 for gas or condensate reservoirs
To obtain a dimensionless error term. A value less than 0.1 usually indicates an acceptable match.
For the multi-tank case the standard deviation is the total error in pressure divided by the number of points in the regression

4. To use the regression results for one of the parameters as a starting point for the next regression, click the

   ◀ button (for single tanks) or the
   <<< button (for multi-tanks) in the centre column between the values. The program will copy the value across.

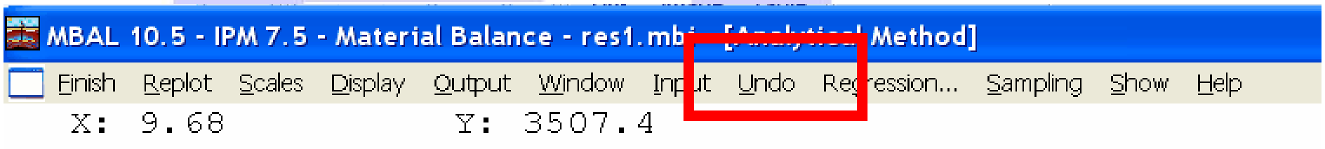
5. To transfer all the parameters at once, click the

   ◀ button (for single tanks) or the
   <<< button (for multi-tanks) between 'Start' and 'Best fit'.

6. Start a new regression by clicking **Calc**.

7. Return to the plot by closing the current dialogue box. The program will automatically copy the values in the centre column into the fields of 'Reservoir Parameters' and 'Water Influx' dialogue boxes. The program will then immediately recalculate the new production. The plot now shows the production calculated using the latest set of parameters.

Should the regression results be unsatisfactory, a new option is available in **IPM 7**; an 'undo' button has been added which allows the regressed data to be ignored and the originally input values are left unaltered:

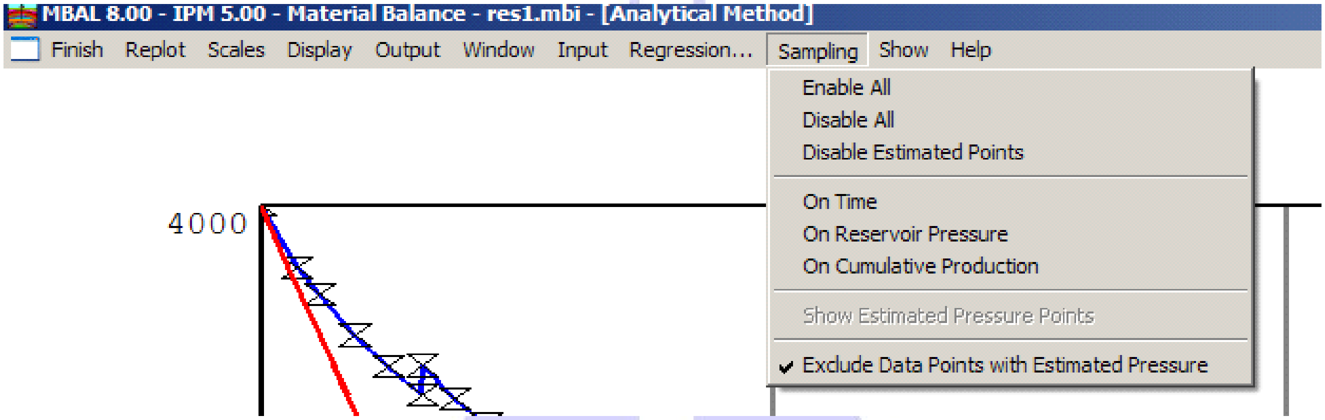


Command Buttons

Calc	Start the regression calculation
Reset	This button re-initialises the regression starting values to the original set of reservoir and aquifer parameters entered in the Reservoir Parameters and Water Influx dialogue boxes

2.4.5.2.2 History Points Sampling

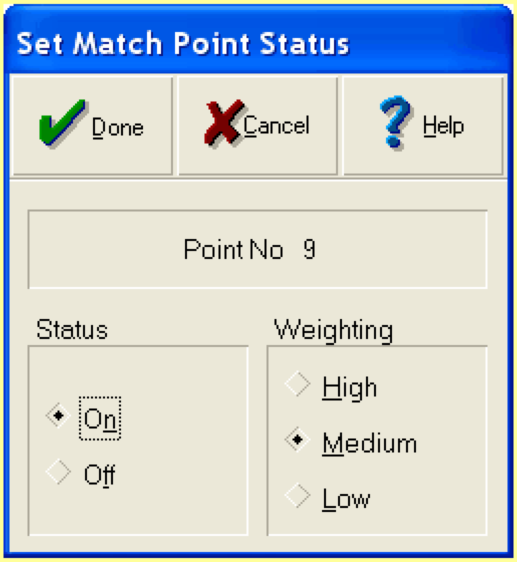
It is sometime an advantage in the first stages of a study to reduce the number of history data points used in the regression. **MBAL** automatically reduces the number points used in the regression to 10. Depending on the menu option selected, the program will sample the data based on 'equal' time, cumulative production or pressure steps.


MBAL 8.00 - IPM 5.00 - Material Balance - res1.mbi - [Analytical Method]
Finish
Replot
Scales
Display
Output
Window
Input
Regression...
Sampling
Show
Help
Enable All
Disable All
Disable Estimated Points
On Time
On Reservoir Pressure
On Cumulative Production
Show Estimated Pressure Points
✓ Exclude Data Points with Estimated Pressure
4000

Select the **Sampling** menu option followed by one of the sub-options available, as shown above. The **Enable All** option cancels any sampling previously performed and resets the weighting of all the points to 'medium' (see below).
Refer to weighting for more information.

2.4.5.2.3 Changing the Weighting of History Points in the Regression

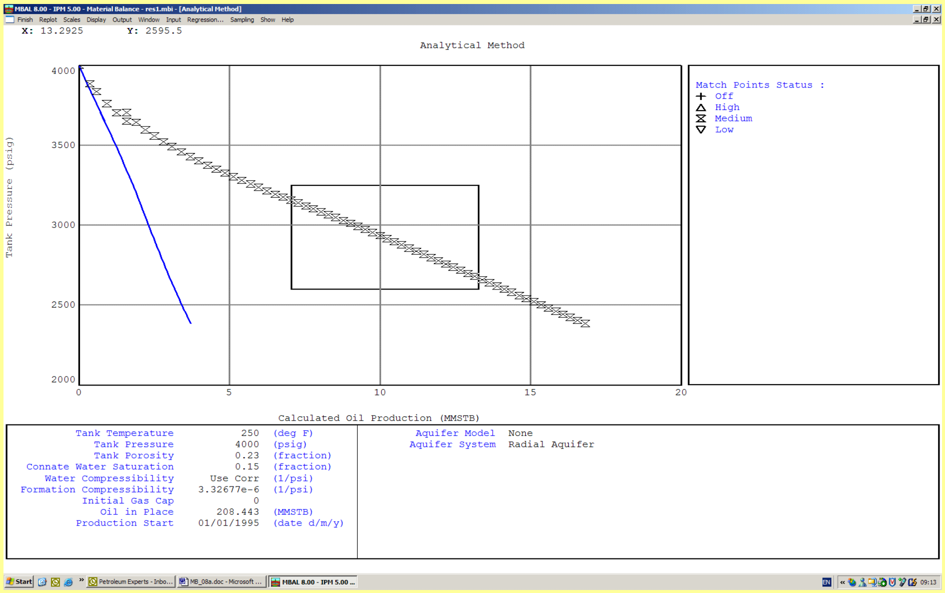
Each data point can be given a different weighting during the regression. Data points considered to be more accurate than others can be set to HIGH to force the regression to go through these points. Secondary or doubtful data points can be set to '***Low***' or switched '***Off***' completely.

Changing a Single Point	Using the **LEFT** mouse button, double-click the history point to be changed.  Set Match Point Status Done Cancel Help Status Weighting ○ High ○ Low ○ Off Point No 9 Status: ● On Weighting: ● Medium

<table>
<tr>
<td></td>
<td>Choose as required:

- The point weighting (High / Medium / Low) and/or
- Status (Off / On).

Points that are switched off are not included in the regression or production calculations.
Click <i>Done</i> to confirm the changes</td>
</tr>
<tr>
<td>Changing Multiple Points</td>
<td>Using the RIGHT mouse button and dragging the mouse, draw a dotted rectangle over the points to be modified. (This click and drag operation is identical to the operation used to re-size plot displays, but uses the right mouse button.)

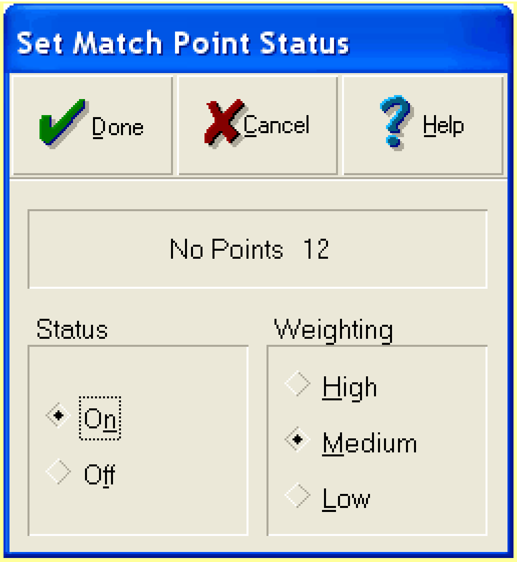

MBAL 8.00 - IPM 5.00 - Material Balance - res1.mbi - [Analytical Method]
Finish Replot Scales Display Output Window Input Regression... Sampling Show Help
X: 13.2925 Y: 2595.5
Analytical Method
Tank Pressure (psig)
4000
3500
3000
2500
2000
0
5
10
15
20
Calculated Oil Production (MMSTB)
Match Points Status :
+ Off
△ High
⧖ Medium
▽ Low
Start
Petroleum Experts - Inbo...
MB_08a.doc - Microsoft ...
MBAL 8.00 - IPM 5.00 ...
EN
09:13

Tank Temperature 250 (deg F)
Tank Pressure 4000 (psig)
Tank Porosity 0.23 (fraction)
Connate Water Saturation 0.15 (fraction)
Water Compressibility Use Corr (1/psi)
Formation Compressibility 3.32677e-6 (1/psi)
Initial Gas Cap 0
Oil in Place 208.443 (MMSTB)
Production Start 01/01/1995 (date d/m/y)
Aquifer Model None
Aquifer System Radial Aquifer

If no right mouse button is available, the button selection can still be performed by using the left mouse button and holding the shift key down while clicking and dragging.

Release the mouse button.

A dialogue box appears displaying the number of points selected.</td>
</tr>
</table>


Set Match Point Status
Done
Cancel
Help

No Points 12

Status
● On
○ Off

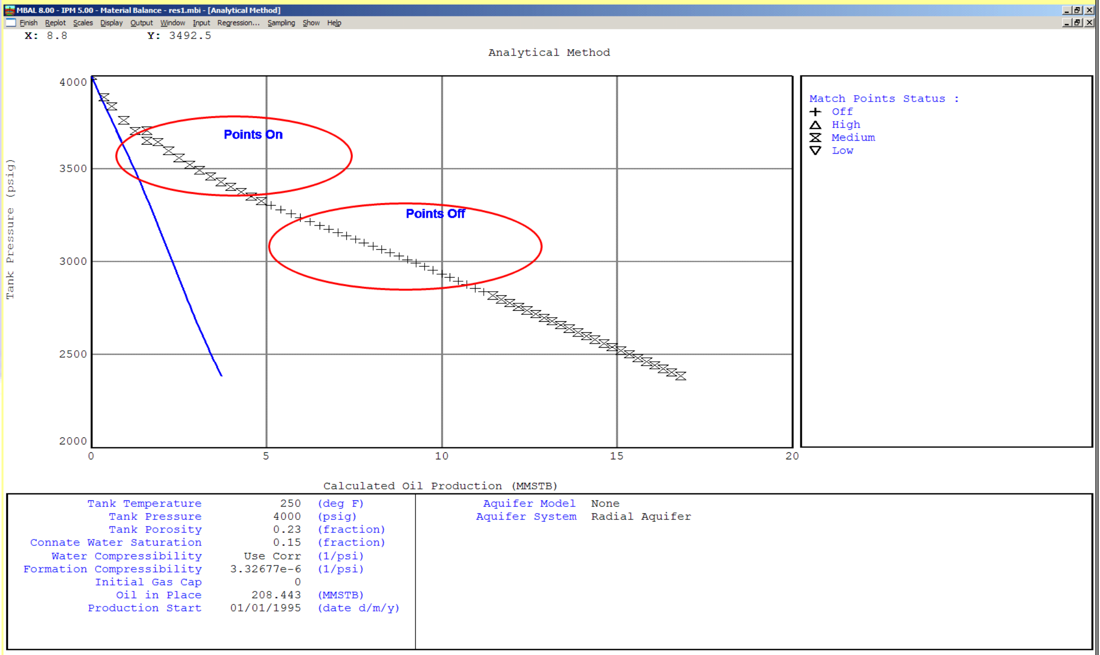
Weighting
○ High
● Medium
○ Low

All the history points included in the 'Drawn' box will be affected by the selections made. Choose as required:

- The point weighting (High / Medium / Low) and/or
- Status (Off / On).

Click ***Done*** to confirm the changes.

All the history points included in the 'drawn' box will be affected by the operation. Choose the points' weighting (High / Medium / Low) and/or status (Off / On) as desired. Click ***Done*** to confirm the changes. If points are switched off, they will appear as shown in the diagram below:


MBAL 8.00 - IPM 5.00 - Material Balance - res1.mbi - [Analytical Method]
Finish Replot Scales Display Output Window Input Regression... Sampling Show Help
X: 8.8
Y: 3492.5
Analytical Method
Tank Pressure (psig)
4000
3500
3000
2500
2000
0
5
10
15
20
Calculated Oil Production (MMSTB)
Points On
Points Off
Match Points Status :
+ Off
△ High
⧖ Medium
▽ Low

```
          Tank Temperature         250  (deg F)          Aquifer Model  None
             Tank Pressure        4000  (psig)          Aquifer System  Radial Aquifer
             Tank Porosity        0.23  (fraction)
  Connate Water Saturation        0.15  (fraction)
     Water Compressibility    Use Corr  (1/psi)
 Formation Compressibility 3.32677e-6  (1/psi)
          Initial Gas Cap            0
              Oil in Place     208.443  (MMSTB)
          Production Start  01/01/1995  (date d/m/y)
```

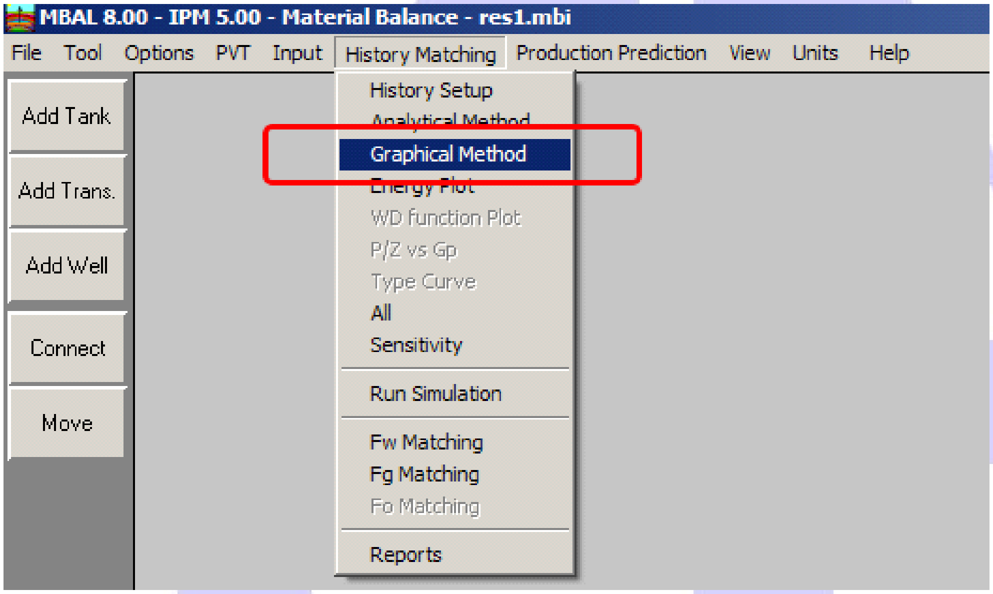
Calculations behind the plot

The calculations related to this plot can be viewed or printed by selecting **Output** followed by the **Results** option in the plot menu.

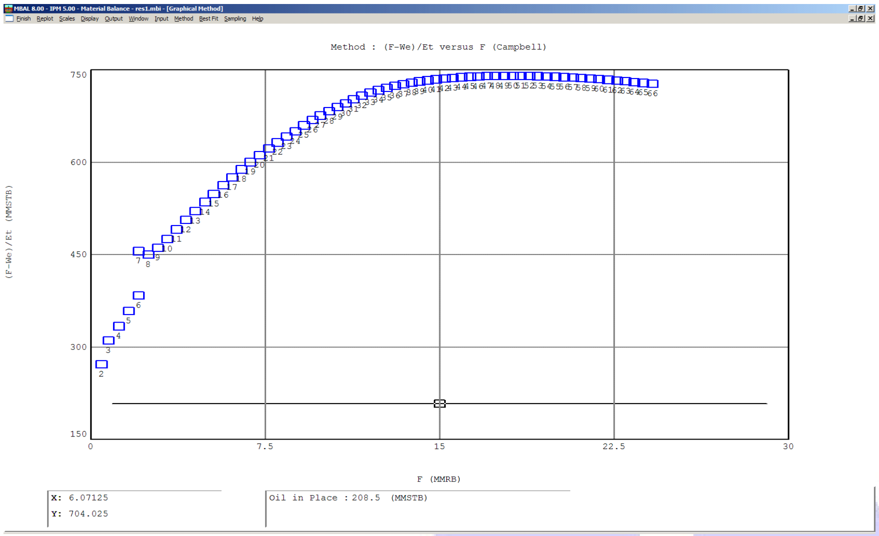
- Only portions of the results can be shown at one time because of the large amount of data to be displayed.
- To view the complete results, use the horizontal and vertical scroll bars to browse through the rest of the calculations.
- Click the **Report** button to send the results directly to the printer, the Windows clipboard or save the report to file.

2.4.5.3 Graphical Method

This graphical method plot is used to visually determine the different reservoir and aquifer parameters. To access the graphical method plot, choose History Matching|Graphical Method:


MBAL 8.00 - IPM 5.00 - Material Balance - res1.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Add Tank
Add Trans.
Add Well
Connect
Move
History Setup
Analytical Method
Graphical Method
Energy Plot
WD function Plot
P/Z vs Gp
Type Curve
All
Sensitivity
Run Simulation
Fw Matching
Fg Matching
Fo Matching
Reports

The following is a typical graphical method plot:


MBAL 8.00 - IPM 5.00 - Material Balance - res1.mbi - [Graphical Method]
Finish Replot Scales Display Output Window Input Method Best Fit Sampling Help
Method : (F-We)/Et versus F (Campbell)
750
600
450
300
150
(F-We)/Et (MMSTB)
0
7.5
15
22.5
30
F (MMRB)

X: 6.07125
Y: 704.025

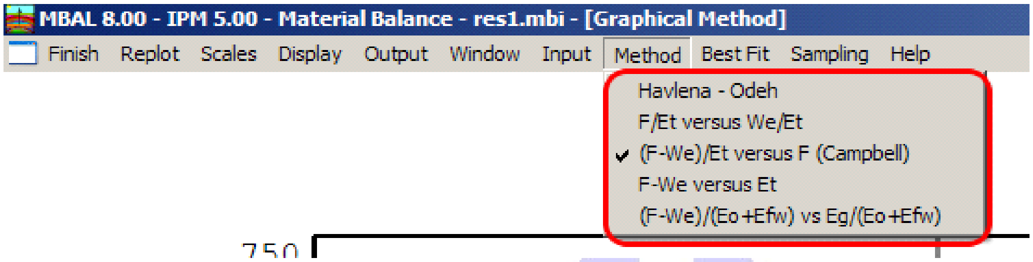
Oil in Place : 208.5 (MMSTB)

The following different methods are available:

For Oil reservoirs	• Havlena-Odeh • F/E versus We/Et • (F-We)/Et versus F (Campbell) • F-We versus Et • (F-We)/(Eo+Efw) vs Eg/(Eo+Efw) • F/Et versus F (Campbell - No Aquifer)
For Gas/ Condensate reservoirs	• P/Z • P/Z (over pressured) • Havlena - Odeh (over -pressured) • Havlena - Odeh (water drive) • (F-We)/Et (Cole) • Roach (unknown compressibility) • F/Et (Cole - No Aquifer)

For a more detailed description of each method, please refer to the appendices and relevant literature. The examples (Examples guide 512) also provide some detail with regards to Campbell or Cole plots in particular)

The different plots can be selected from the graphical plot menu as shown below:


MBAL 8.00 - IPM 5.00 - Material Balance - res1.mbi - [Graphical Method]
Finish
Replot
Scales
Display
Output
Window
Input
Method
Best Fit
Sampling
Help
Havlena - Odeh
F/Et versus We/Et
✓ (F-We)/Et versus F (Campbell)
F-We versus Et
(F-We)/(Eo+Efw) vs Eg/(Eo+Efw)
750

The aim of most graphical methods is to align all the data points on a straight line. The intersection of this straight line with one of the axes (and, in some cases the slope of the straight line) gives some information about the hydrocarbons in place.

For this purpose, a 'straight line tool' is provided to attain this information. This line 'tool' can be moved or placed anywhere on the plot. Depending on the method selected, the slope of the line (when relevant) and its intersection with either the X axis or Y axis is displayed at the bottom part of the screen.

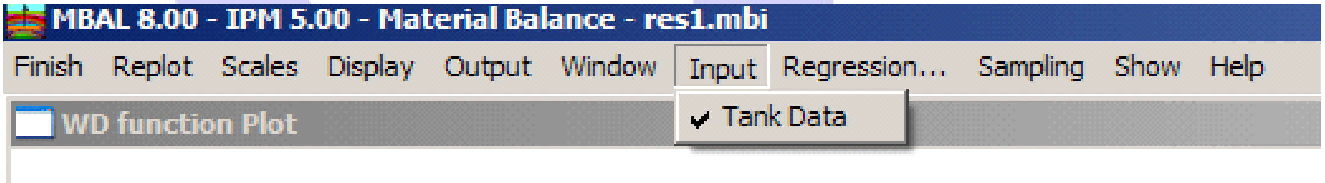
Reservoir, leaks and aquifer parameters can be changed without exiting the plot by clicking the **Input..** menu options. On closing the dialogue box, the program will automatically refresh/ update the plot(s).

Only one tank is plotted at a time - to change the current tank, select **Tanks**, **Previous Tank** or **Next Tank**.

See also General Plotting Options for standard plotting options help.

2.4.5.3.1 Changing the Reservoir and Aquifer Parameters

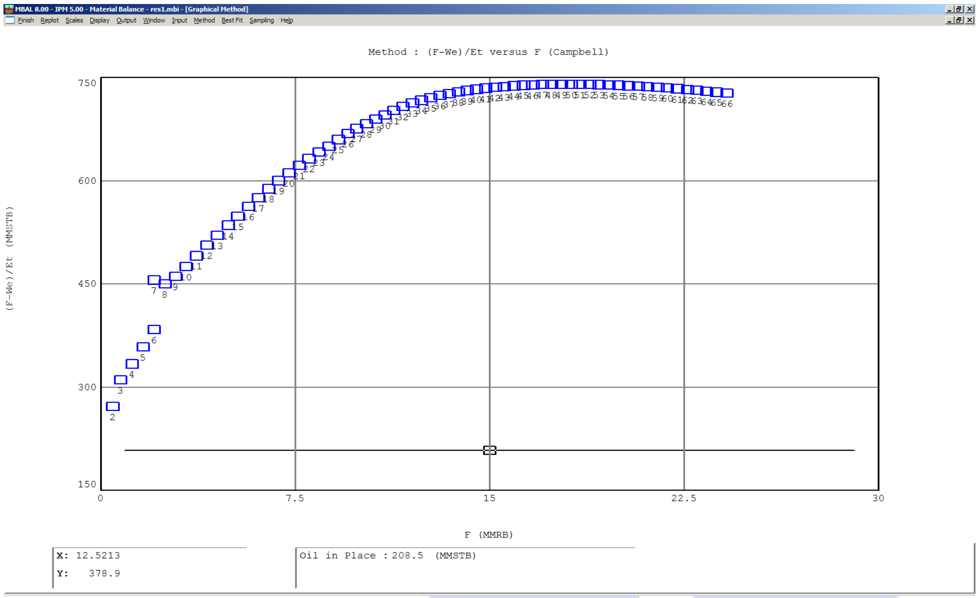
Reservoir, transmissibility and aquifer parameters can be changed without exiting the plot by clicking on the **Input...** menu options:


MBAL 8.00 - IPM 5.00 - Material Balance - res1.mbi
Finish
Replot
Scales
Display
Output
Window
Input
Regression...
Sampling
Show
Help
WD function Plot
✓ Tank Data

On closing the dialogue box, the program will automatically refresh/update the plot(s).

2.4.5.3.2 Straight Line Tool

The graphical method straight line tool is composed of 4 elements: a straight line, and three small squares which are used to move the line around the screen:


MBAL 8.00 - IPM 5.00 - Material Balance - res1.mbi - [Graphical Method]
Finish
Replot
Scales
Display
Output
Window
Input
Method
Best Fit
Sampling
Help
Method : (F-We)/Et versus F (Campbell)
(F-We)/Et (MMSTB)
750
600
450
300
150
0
7.5
15
22.5
30
F (MMRB)

X: 12.5213
Y: 378.9

Oil in Place : 208.5 (MMSTB)

The line can be moved by dragging the square in the middle of the line. Depending on the method chosen, squares may also be seen at the ends of the line which can be moved as well to get a manual fit to the data.

To shift the line	click and drag the square at the centre of the line
To rotate the line	click and drag one of the squares at the end of the line

If the straight line tool disappears or becomes to small due to the change of scales, select RePlot from the plot menu to re-scale the line.
The '**Best Fit**' menu option will automatically find the best fit for the line 'tool', depending on the Graphical Method used.

Depending on the graphical method used, some squares may be hidden. For example, the **F/Et vs. Et** plot for the oil reservoir should, when a good match is achieved, show a horizontal line.

In this case, the line 'tool' can only be horizontal and can only be translated vertically. Thus the squares at the end of the line are hidden.

The line 'tool' always represents the latest set of reservoir and aquifer parameters that have been entered or calculated. The line is automatically rotated or translated by the program to reflect the new values according to the graphical method selected.

➡ **Care should be taken when moving the line 'tool'. Moving the line 'tool' also changes the oil or gas in place value in the 'Input Reservoir Parameters' dialogue box.**

The calculations related to this plot can be viewed or printed by clicking **Output | Results** from the plot menu.

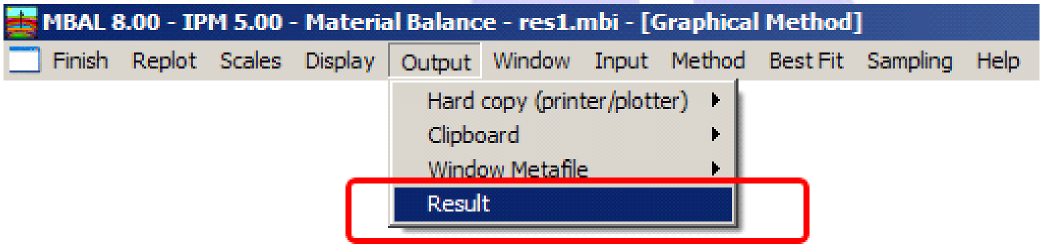
2.4.5.3.3 Locating the Straight Line Tool

If the straight line 'tool' disappears or becomes too small due to a change of scales, double-clicking the centre of the plot will re-scale the line and place it across the plot.

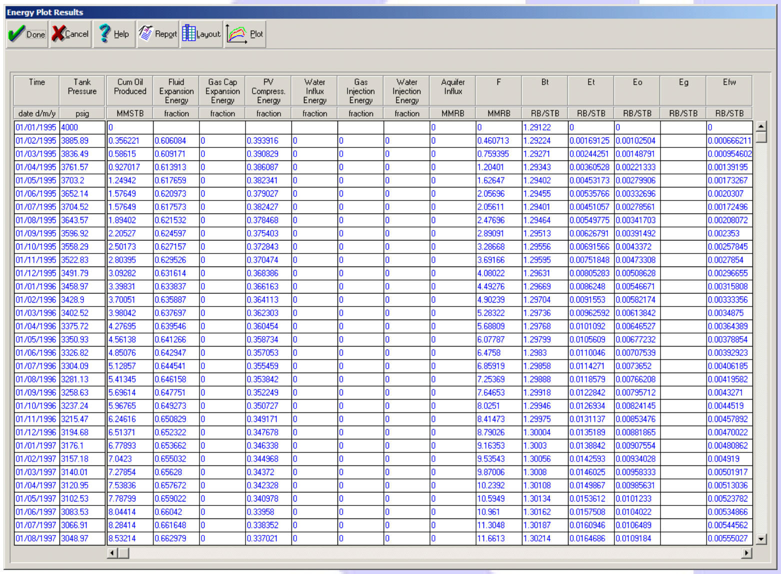
2.4.5.3.4 Graphical method results

The calculations related to this plot can be viewed or printed by clicking **Output | Results** from the plot menu.

- Only portions of the results can be shown at one time because of the huge amount of data to be displayed.
- To browse through the results, use the horizontal and vertical scroll bars.
- Click the **Report** button to send the results directly to the printer, the Windows clipboard or save the results to file.


MBAL 8.00 - IPM 5.00 - Material Balance - res1.mbi - [Graphical Method]
Finish
Replot
Scales
Display
Output
Window
Input
Method
Best Fit
Sampling
Help
Hard copy (printer/plotter)
Clipboard
Window Metafile
Result

The **Results** screen shows the 'Expansion', 'Underground Withdrawa', 'Aquifer influx' etc. values for each match point:



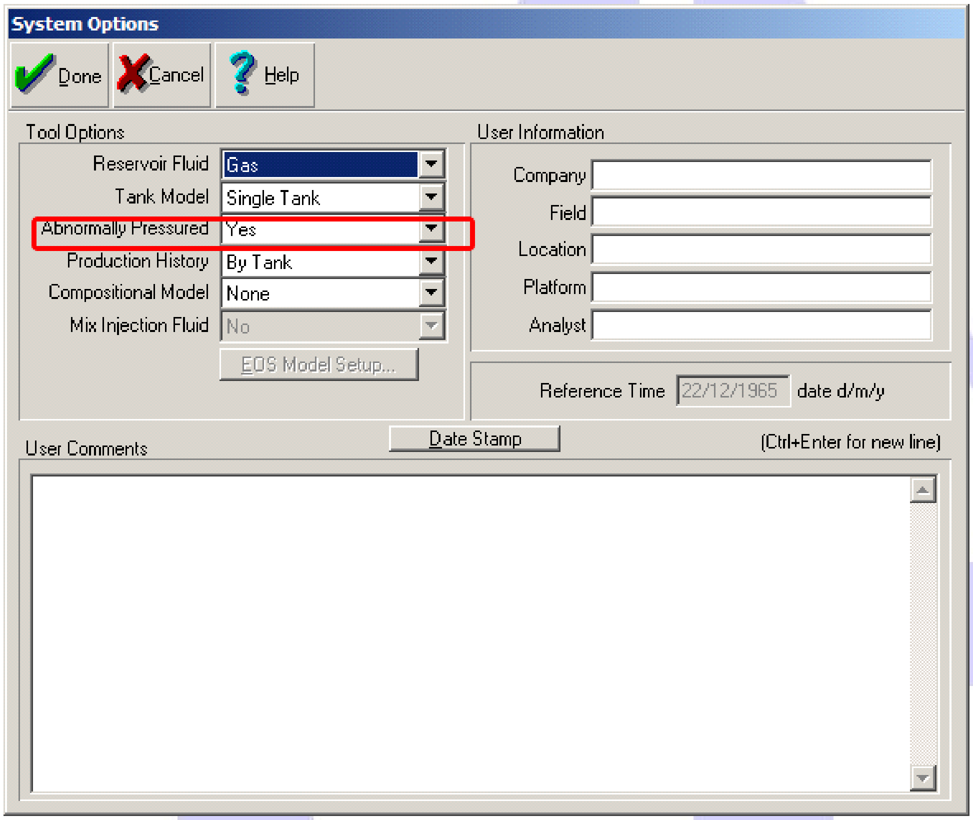
Time	Tank Pressure	Cum Oil Produced	Fluid Expansion Energy	Gas Cap Expansion Energy	PV Compress. Energy	Water Influx Energy	Gas Injection Energy	Water Injection Energy	Aquifer Influx	F	Bt	Et	Eo	Eg	Efw
date d/m/y	psig	MMSTB	fraction	fraction	fraction	fraction	fraction	fraction	MMRB	MMRB	RB/STB	RB/STB	RB/STB	RB/STB	RB/STB
01/01/1995	4000	0							0	0	1.29122	0	0		0
01/02/1995	3885.89	0.356221	0.606084	0	0.393916	0	0	0	0	0.460713	1.29224	0.00169125	0.00102504		0.000666211
01/03/1995	3836.49	0.58615	0.609171	0	0.390829	0	0	0	0	0.759395	1.29271	0.00244251	0.00148791		0.000954602
01/04/1995	3761.57	0.927017	0.613913	0	0.386087	0	0	0	0	1.20401	1.29343	0.00360528	0.00221333		0.00139195
01/05/1995	3703.2	1.24942	0.617659	0	0.382341	0	0	0	0	1.62647	1.29402	0.00453173	0.00279906		0.00173267
01/06/1995	3652.14	1.57649	0.620973	0	0.379027	0	0	0	0	2.05696	1.29455	0.00535766	0.00332696		0.0020307
01/07/1995	3704.52	1.57649	0.617573	0	0.382427	0	0	0	0	2.05611	1.29401	0.00451057	0.00278561		0.00172496
01/08/1995	3643.57	1.89402	0.621532	0	0.378468	0	0	0	0	2.47696	1.29464	0.00549775	0.00341703		0.00208072
01/09/1995	3596.92	2.20527	0.624597	0	0.375403	0	0	0	0	2.89091	1.29513	0.00626791	0.00391492		0.002353
01/10/1995	3558.29	2.50173	0.627157	0	0.372843	0	0	0	0	3.28668	1.29556	0.00691566	0.0043372		0.00257845
01/11/1995	3522.83	2.80395	0.629526	0	0.370474	0	0	0	0	3.69166	1.29595	0.00751848	0.00473308		0.0027854
01/12/1995	3491.79	3.09282	0.631614	0	0.368386	0	0	0	0	4.08022	1.29631	0.00805283	0.00508628		0.00296655
01/01/1996	3458.97	3.39831	0.633837	0	0.366163	0	0	0	0	4.49276	1.29669	0.0086248	0.00546671		0.00315808
01/02/1996	3428.9	3.70051	0.635887	0	0.364113	0	0	0	0	4.90239	1.29704	0.0091553	0.00582174		0.00333356
01/03/1996	3402.52	3.98042	0.637697	0	0.362303	0	0	0	0	5.28322	1.29736	0.00962592	0.00613842		0.0034875
01/04/1996	3375.72	4.27695	0.639546	0	0.360454	0	0	0	0	5.68809	1.29768	0.0101092	0.00646527		0.00364389
01/05/1996	3350.93	4.56138	0.641266	0	0.358734	0	0	0	0	6.07787	1.29799	0.0105609	0.00677232		0.00378854
01/06/1996	3326.82	4.85076	0.642947	0	0.357053	0	0	0	0	6.4758	1.2983	0.0110046	0.00707539		0.00392923
01/07/1996	3304.09	5.12857	0.644541	0	0.355459	0	0	0	0	6.85919	1.29858	0.0114271	0.0073652		0.00406185
01/08/1996	3281.13	5.41345	0.646158	0	0.353842	0	0	0	0	7.25369	1.29888	0.0118579	0.00766208		0.00419582
01/09/1996	3258.63	5.69614	0.647751	0	0.352249	0	0	0	0	7.64653	1.29918	0.0122842	0.00795712		0.0043271
01/10/1996	3237.24	5.96765	0.649273	0	0.350727	0	0	0	0	8.0251	1.29946	0.0126934	0.00824145		0.0044519
01/11/1996	3215.47	6.24616	0.650829	0	0.349171	0	0	0	0	8.41473	1.29975	0.0131137	0.00853476		0.00457892
01/12/1996	3194.68	6.51371	0.652322	0	0.347678	0	0	0	0	8.79026	1.30004	0.0135189	0.00881865		0.00470022
01/01/1997	3176.1	6.77893	0.653662	0	0.346338	0	0	0	0	9.16353	1.3003	0.0138842	0.00907554		0.00480862
01/02/1997	3157.18	7.0423	0.655032	0	0.344968	0	0	0	0	9.53543	1.30056	0.0142593	0.00934028		0.004919
01/03/1997	3140.01	7.27854	0.65628	0	0.34372	0	0	0	0	9.87006	1.3008	0.0146025	0.00958333		0.00501917
01/04/1997	3120.95	7.53836	0.657672	0	0.342328	0	0	0	0	10.2392	1.30108	0.0149867	0.00985631		0.00513036
01/05/1997	3102.53	7.78799	0.659022	0	0.340978	0	0	0	0	10.5949	1.30134	0.0153612	0.0101233		0.00523782
01/06/1997	3083.53	8.04414	0.66042	0	0.33958	0	0	0	0	10.961	1.30162	0.0157508	0.0104022		0.00534866
01/07/1997	3066.91	8.28414	0.661648	0	0.338352	0	0	0	0	11.3048	1.30187	0.0160946	0.0106489		0.00544562
01/08/1997	3048.97	8.53214	0.662979	0	0.337021	0	0	0	0	11.6613	1.30214	0.0164686	0.0109184		0.00555027

2.4.5.3.5 Abnormally pressured gas reservoirs

For a case in which a gas reservoir is abnormally pressured, a model based on SPE 71514 “A Semianalytical p/z Technique for the Analysis of Reservoir Performance from Abnormally Pressured Gas Reservoirs” has been added to provide a means of modeling this situation.

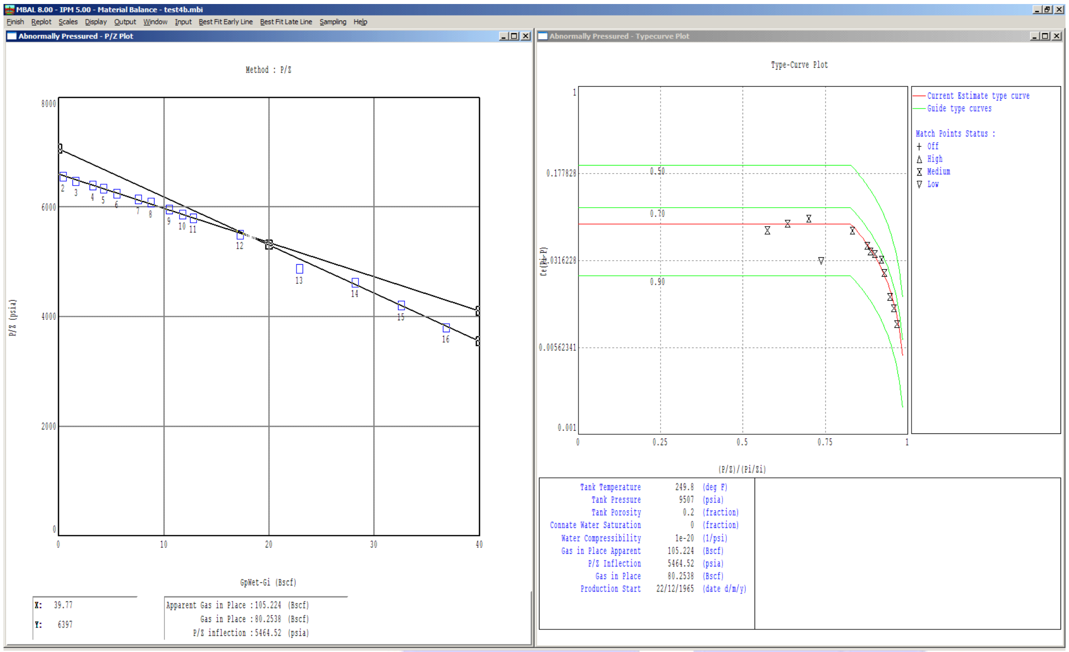
It is recommended that this paper is studied before using this method.

The method is activated from the 'Options' menu:


System Options
Done
Cancel
Help
Tool Options
User Information
Company
Field
Location
Platform
Analyst
EOS Model Setup...
User Comments
Date Stamp
(Ctrl+Enter for new line)

Reservoir Fluid: Gas
Tank Model: Single Tank
Abnormally Pressured: Yes
Production History: By Tank
Compositional Model: None
Mix Injection Fluid: No
Reference Time: 22/12/1965 date d/m/y

The model can be used when two straight lines are observed in the P/Z plot. Two plots will be available for this method. One is the abnormally pressured P/Z plot and the other is the type curve plot:


MBAL 8.00 - IPM 5.00 - Material Balance - test4b.mbi
Finish
Replot
Scales
Display
Output
Window
Input
Best Fit Early Line
Best Fit Late Line
Sampling
Help
Abnormally Pressured - P/Z Plot
Method : P/Z
8000
6000
4000
2000
0
P/Z (psia)
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
0
10
20
30
40
GpWet-Gi (Bscf)
Abnormally Pressured - Typecurve Plot
Type-Curve Plot
1
0.177828
0.0316228
0.00562341
0.001
Ce(Pi-P)
0.50
0.70
0.90
0
0.25
0.5
0.75
1
(P/Z)/(Pi/Zi)
Current Estimate type curve
Guide type curves
Match Points Status :
+ Off
Δ High
X Medium
∇ Low

X: 39.77

Y: 6397

Apparent Gas in Place : 105.224 (Bscf)

Gas in Place : 80.2538 (Bscf)

P/Z inflection : 5464.52 (psia)

Tank Temperature	249.8	(deg F)
Tank Pressure	9507	(psia)
Tank Porosity	0.2	(fraction)
Connate Water Saturation	0	(fraction)
Water Compressibility	1e-20	(1/psi)
Gas in Place Apparent	105.224	(Bscf)
P/Z Inflection	5464.52	(psia)
Gas in Place	80.2538	(Bscf)
Production Start	22/12/1965	(date d/m/y)

P/Z Plot description

The early line develops during the abnormally pressured behavior. The line must intersect the initial P/Z. The intersection with the X axis defines the **OGIP apparent**.

The late line develops once the abnormally pressured behavior has stopped. This is the normal P/Z line expected due to gas expansion only. The intersection gives the **true OGIP** as normal.

The intersection between the two lines occurs at P/Z Inflection which is the pressure point at which the reservoir has been considered to have stopped compacting.

An automatic regression could be carried out to fit both of the lines. First select the range of the data to which the line is to be fitted. To do this select two points by double-clicking on them. Then click on either **Best Fit Early Line** or **Best Fit Late Line** menu item. The fit will be performed on the data between the two selected points. Remember that the early line will always be forced through the initial P/Z.

Alternatively the lines could be moved manually. These lines have three handles shown as small squares which can be selected to move the line up and down (but keeping the slope constant) by clicking and dragging the middle line handle. Alternatively the line can be rotated by clicking and dragging on of the end handles. Since the early line must intersect the initial P/Z, only the end handle can be moved to rotate the line around the P/Z initial point.

Type Curve Plot description

The data is presented on a plot of Ce(Pi-P) vs (P/Z)/(P/Z)i. The Ce(Pi-P) functions increase as pressure decreases until it reaches its constant maximum value at and below P/Z inflection.

Three type curves coloured in green are displayed to help guide the user to a solution. The three curves have different values of OGIP actual / OGIP apparent. The value of this ratio is written next to the curve.

The type curve in red has the current value of OGIP actual / OGIP apparent.

The purpose of the plot is to allow the user to modify the three input values to the compressibility model:

- OGIP Apparent
- OGIP Actual
- P/Z Inflection

To obtain the best match between the plotted data and the actual type curve (displayed in green).

The values can be changed in two ways:

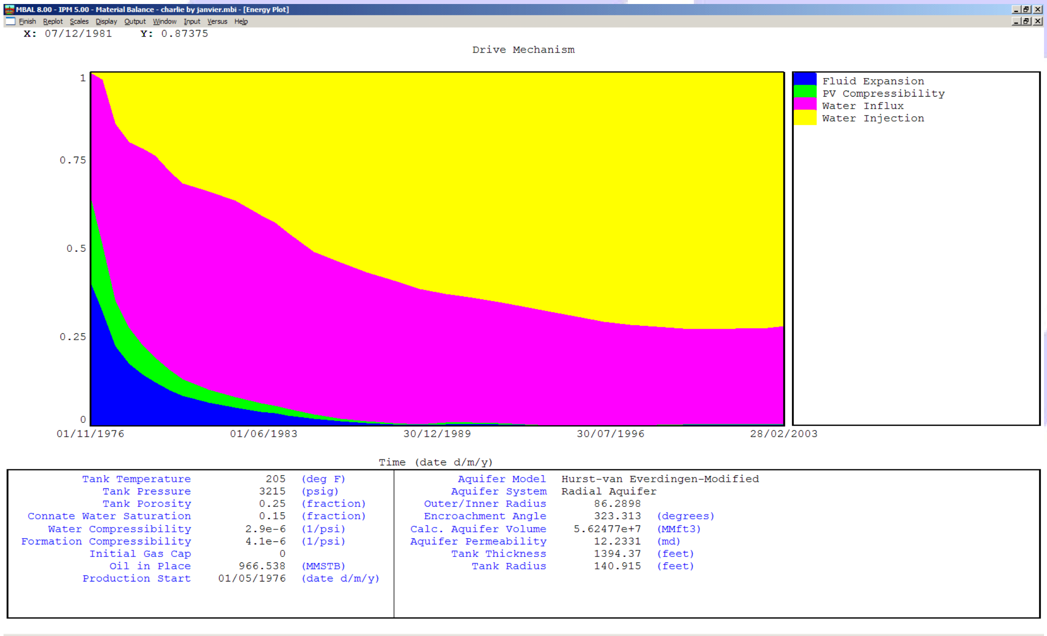
- Click on the 'Tune' menu item. This will allow the three input values to manually altered.
- Click on the 'Regression' menu item. This will allow a numerical regression to be carried out, to obtain the best input values automatically. WARNING this method should only be used after obtaining good first estimates by the manual methods.

2.4.5.4 Energy Plot

This plot shows the relative contributions of the main source of energy in the reservoir and aquifer system.

It does not in itself provide the user with detailed information, but indicates very clearly which parameters and properties should be focused on (i.e. PVT, Formation Compressibility, Water Influx.). For example, if the 'Water Influx' area (normally red) is very small then the aquifer properties could be ignored to focus on other areas

Consider the following plot:


MBAL 8.00 - IPM 5.00 - Material Balance - charlie by janvier.mbi - [Energy Plot]
Finish Replot Scales Display Output Window Input Versus Help
X: 07/12/1981 Y: 0.87375
Drive Mechanism
1
0.75
0.5
0.25
0
01/11/1976
01/06/1983
30/12/1989
30/07/1996
28/02/2003
Time (date d/m/y)
Fluid Expansion
PV Compressibility
Water Influx
Water Injection

Tank Temperature	205	(deg F)
Tank Pressure	3215	(psig)
Tank Porosity	0.25	(fraction)
Connate Water Saturation	0.15	(fraction)
Water Compressibility	2.9e-6	(1/psi)
Formation Compressibility	4.1e-6	(1/psi)
Initial Gas Cap	0	
Oil in Place	966.538	(MMSTB)
Production Start	01/05/1976	(date d/m/y)

Aquifer Model	Hurst-van Everdingen-Modified	
Aquifer System	Radial Aquifer	
Outer/Inner Radius	86.2898	
Encroachment Angle	323.313	(degrees)
Calc. Aquifer Volume	5.62477e+7	(MMft3)
Aquifer Permeability	12.2331	(md)
Tank Thickness	1394.37	(feet)
Tank Radius	140.915	(feet)

At the beginning of history, some energy comes from the expansion of the fluid in place, whereas towards the end of history, a negligible drive comes from the hydrocarbon expansion. Therefore, when trying to history match and get the OOIP the initial production points should be focussed on, not the points at the end of history.

Reservoir, transmissibility and aquifer parameters can be changed without exiting the plot by clicking the **Input..** menu options. On closing the dialogue box, the program will automatically refresh/update the plot(s).

Only one tank is plotted at a time - to change the current tank, select **Tanks**, **Previous Tank** or **Next Tank**.

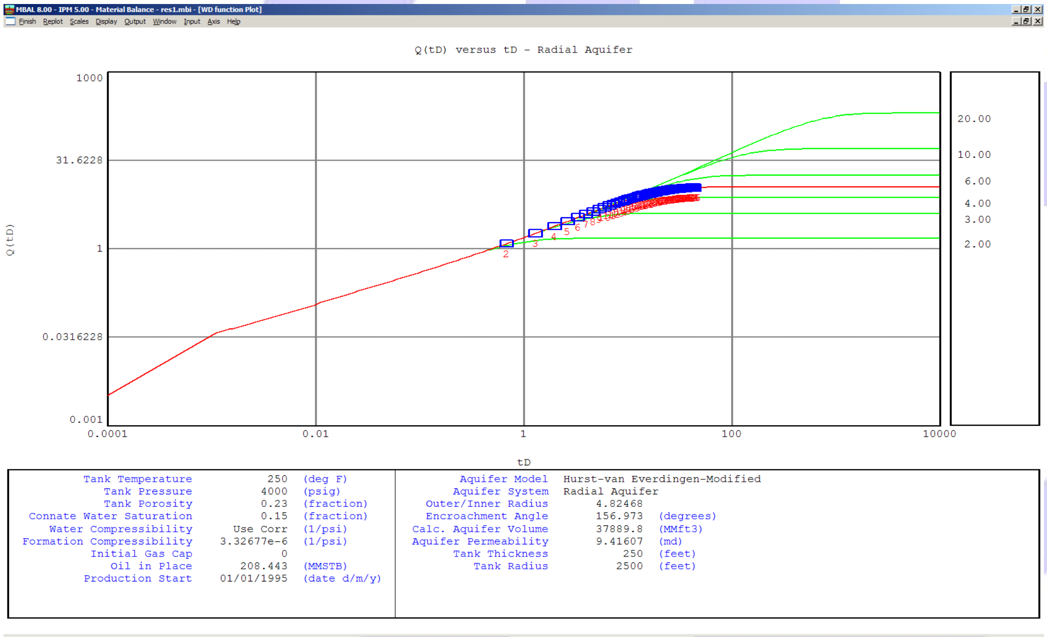
2.4.5.5 WD Function Plot

The WD plot shows the dimensionless aquifer function versus dimensionless time type curves. This plot also indicates the location of the history data points in dimensionless co-ordinates.

Linear and logarithmic axes are available. Select the **Axis** menu item to change the axis type.

➡ **This plot is only available with some aquifer types. A Small Pot aquifer model for example does not have such a plot because of the simplicity of its formulation.**

A typical plot will look like this:


MBAL 8.00 - IPM 5.00 - Material Balance - res1.mbi - [WD function Plot]
Finish Replot Scales Display Output Window Input Axis Help
Q(tD) versus tD - Radial Aquifer
1000
31.6228
1
0.0316228
0.001
Q(tD)
0.0001
0.01
1
100
10000
tD
20.00
10.00
6.00
4.00
3.00
2.00
2
3
4
5
6

```
          Tank Temperature         250   (deg F)            Aquifer Model   Hurst-van Everdingen-Modified
             Tank Pressure        4000   (psig)            Aquifer System   Radial Aquifer
             Tank Porosity        0.23   (fraction)    Outer/Inner Radius        4.82468
 Connate Water Saturation         0.15   (fraction)    Encroachment Angle        156.973   (degrees)
    Water Compressibility     Use Corr   (1/psi)     Calc. Aquifer Volume        37889.8   (MMft3)
Formation Compressibility  3.32677e-6   (1/psi)     Aquifer Permeability        9.41607   (md)
          Initial Gas Cap            0                     Tank Thickness            250   (feet)
             Oil in Place      208.443   (MMSTB)              Tank Radius           2500   (feet)
         Production Start   01/01/1995   (date d/m/y)
```

Changing r_D parameters

For radial aquifers, the r_D parameters (ratio of outer aquifer radius to inner aquifer radius) can be changed on the plot.

To change the current r_D parameters, position the cursor in the value range nearest to the desired the point of investigation and double-click the LEFT mouse button. The program immediately runs a short regression on the r_D to find the type curve passing through the selected point.

The program will not calculate r_D parameters for points selected below the minimum displayed r_D value. An infinite WD solution curve will be calculated for points selected above the maximum displayed r_D value.

Other Commands

Reservoir, transmissibility and aquifer parameters can be changed without exiting the plot by clicking the **Input..** menu options. On closing the dialogue box, the program will automatically refresh/update the plot(s).

Only one tank is plotted at a time - to change the current tank, select **Tanks**, **Previous Tank** or **Next Tank**.

See also General Plotting Options for standard plotting options help.

2.4.5.6 Simulation

This dialogue box is used for running a production history simulation based on the tanks and aquifer models that have been tuned with the graphical and/or analytical methods.

The simulation calculations can serve as a final quality check on the history matching carried out earlier.

The calculations assume the productions from the history data entered, and iterate at each time step to calculate the reservoir pressure and water influx. Only the times/dates entered in the history are displayed, even though the program uses smaller time increments to calculate.

The analytical method plot uses the reservoir pressures entered in the historical data and calculates the production while the simulation does the opposite. The rates are used from the historical data and the reservoir pressure is calculated based on the material balance model.

Running a simulation

As the simulation is relatively slow, the program **does not** run the simulation automatically as it does with graphical and analytical methods. To start the simulation, click **Calc**.

The simulation will stop automatically when it reaches the last point entered for the pressure/ production history. To browse through the results, use the scroll bars to the right and bottom of the screen. All calculations are retained in program memory and in the data file, allowing the user to leave this screen and return to it later to check the calculations.

The results of the simulation may be stored in a 'stream' and labelled using the dialogue accessed by the 'Save' button. This will allows a comparison between simulations or predictions on the results plots.

Make sure a new simulation is run each time the PVT or the main set of reservoir, aquifer parameters are changed

One method to speed up the calculation is to increase the calculation step size. The default is 15 days. To change this value, select the **History Matching | History Setup** menu. Change *the History Step Size* setting to *User Defined* and enter a large number e. g. 1000 days. This will cause the simulation to only use the entered times for the calculations instead of using 15 day sub-steps. However it is inevitable that this will reduce the accuracy of the calculations particularly if there is a large aquifer or data points are far apart - so it is advised to go back to the smaller time steps once a reasonable estimate has been found

Streams

This dialogue can also be used to display other results. Each set of results is stored in a **stream** . There are always three streams present by default:

- **Production history**
- **The last history simulation**
- **The last production prediction**

Copies of the current history simulation calculations can be made using the **Save** button. This will create a new stream.

To change the stream displayed, change the selection in the **stream** combo-box at the top left of the dialogue.

For single tank cases, each stream corresponds to the one and only tank.

For multi-tank systems, the list of streams is more complex. Within each stream there are additional items called **sheets**. Each sheet corresponds to a tank or transmissibility. It is also possible to select a sheet to display in the streams combo-box. The results displayed if the user selects the stream (rather than one of its sheets) are the consolidated results i.e. the cumulative results from all the tanks.

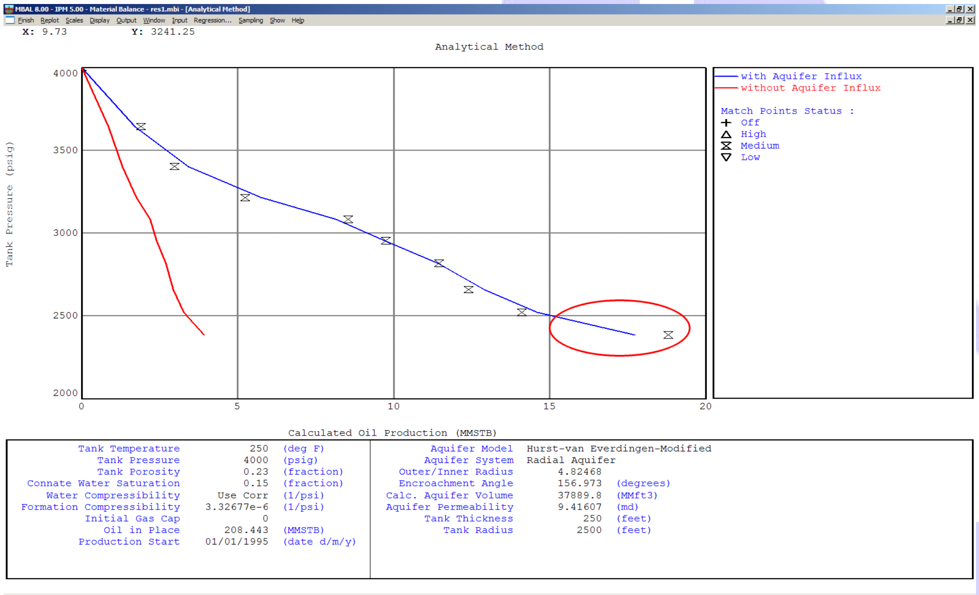
Command Buttons

Report	Allows the user to create listings of the production history simulation
Layout	The layout button allows the user to display a selection of the variables of interest from the calculation results. This option may also be used for printing reports
Plot	This options displays a plot. The user may choose to graph the current production history simulation as well as compare it with any other stored stream/sheets of data
Calc	This option is used to re-calculate the production history simulation using the current input data

Save	This options displays a dialogue that can be used to create a copy of the main Simulation stream. It is then possible to change the input data, re-run the simulation and compare it against the copy of the original simulation. See Saving Prediction/Simulation Results for more information

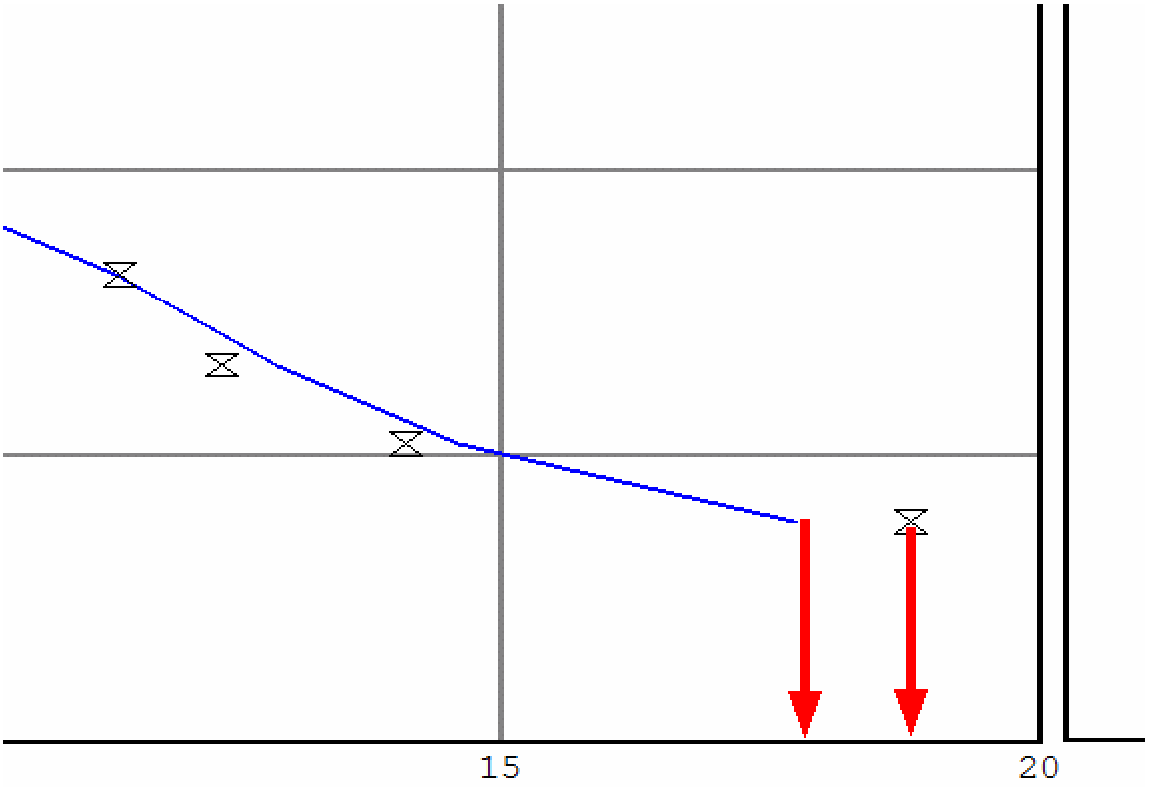
Example of results of a Simulation vs Analytical plot

Consider the following example where the analytical method gives the analytical plot shown below:

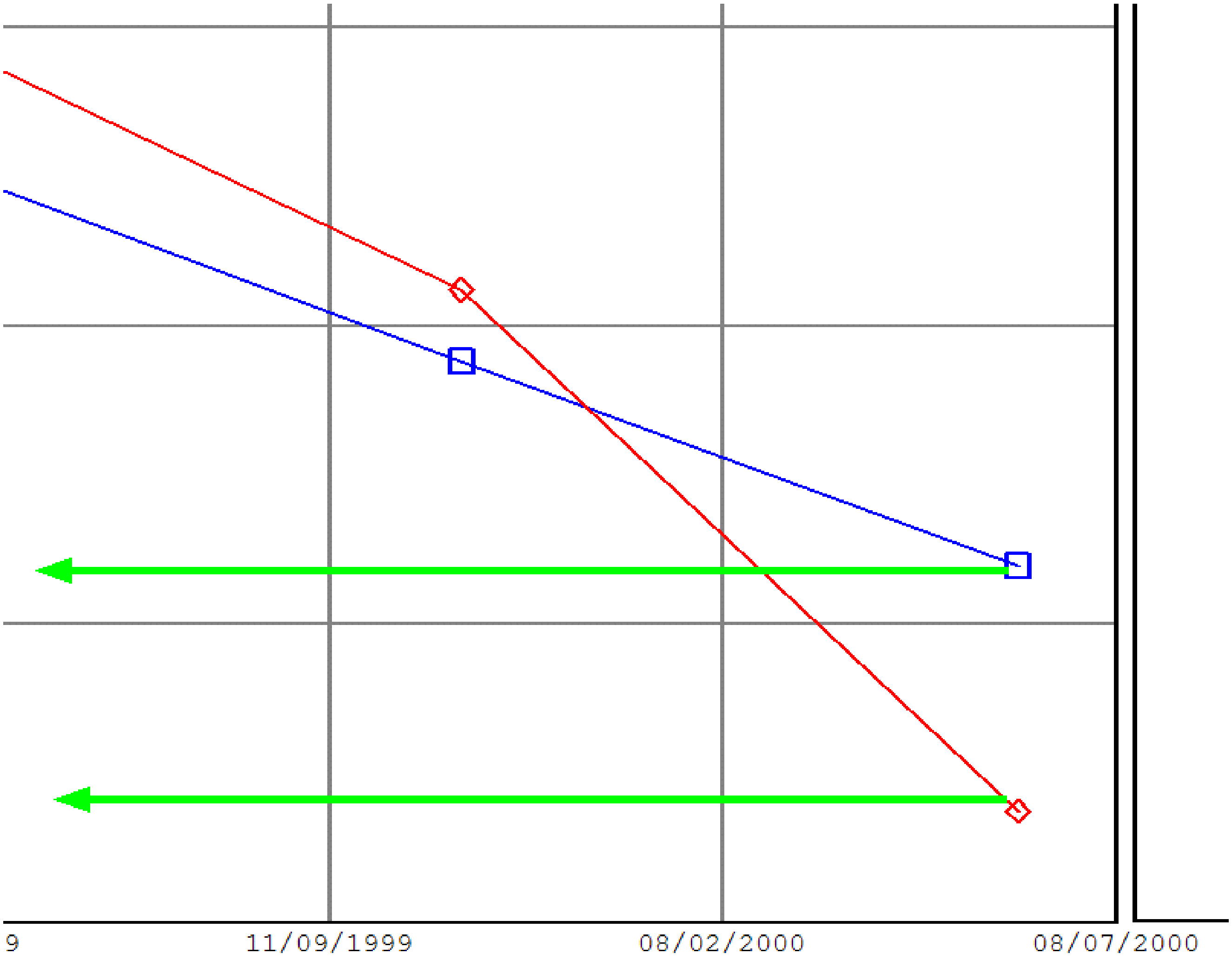

MBAL 8.00 - IPM 5.00 - Material Balance - res1.mbi - [Analytical Method]
Finish
Replot
Scales
Display
Output
Window
Input
Regression...
Sampling
Show
Help
X: 9.73
Y: 3241.25
Analytical Method
Tank Pressure (psig)
4000
3500
3000
2500
2000
0
5
10
15
20
Calculated Oil Production (MMSTB)
with Aquifer Influx
without Aquifer Influx
Match Points Status :
+ Off
△ High
⧖ Medium
▽ Low

```
           Tank Temperature          250  (deg F)            Aquifer Model  Hurst-van Everdingen-Modified
              Tank Pressure         4000  (psig)            Aquifer System  Radial Aquifer
              Tank Porosity         0.23  (fraction)   Outer/Inner Radius      4.82468
  Connate Water Saturation          0.15  (fraction)   Encroachment Angle      156.973  (degrees)
     Water Compressibility      Use Corr  (1/psi)    Calc. Aquifer Volume      37889.8  (MMft3)
 Formation Compressibility   3.32677e-6  (1/psi)    Aquifer Permeability      9.41607  (md)
           Initial Gas Cap             0                     Tank Thickness          250  (feet)
              Oil in Place       208.443  (MMSTB)               Tank Radius         2500  (feet)
          Production Start    01/01/1995  (date d/m/y)
```

It can be seen from the plot that the match could be considered OK. Let us focus on the last point highlighted above. The error between model and measured data is the difference in oil production, as shown below:



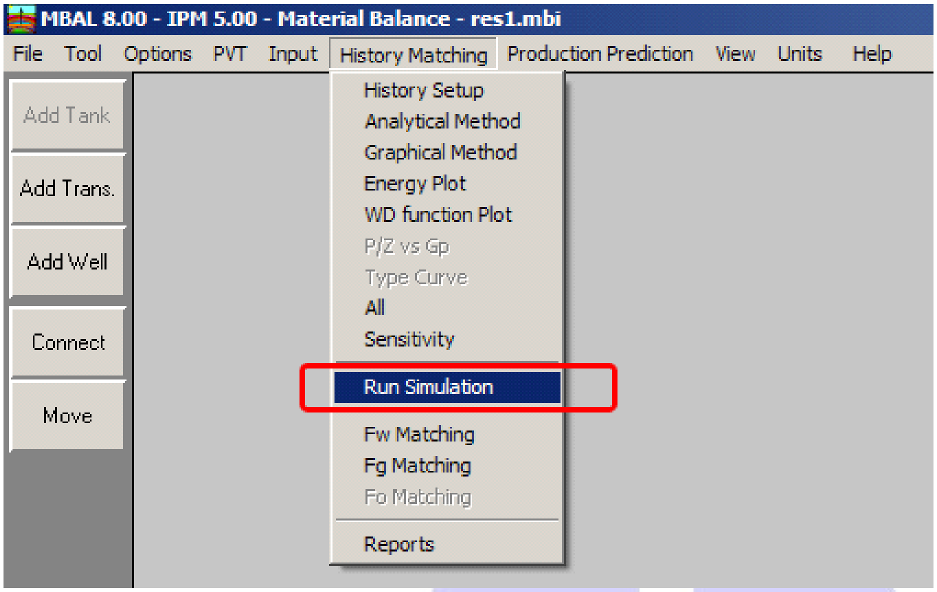
In the simulation plot, the difference, since now the reservoir pressure is the calculated variable will be as shown below:



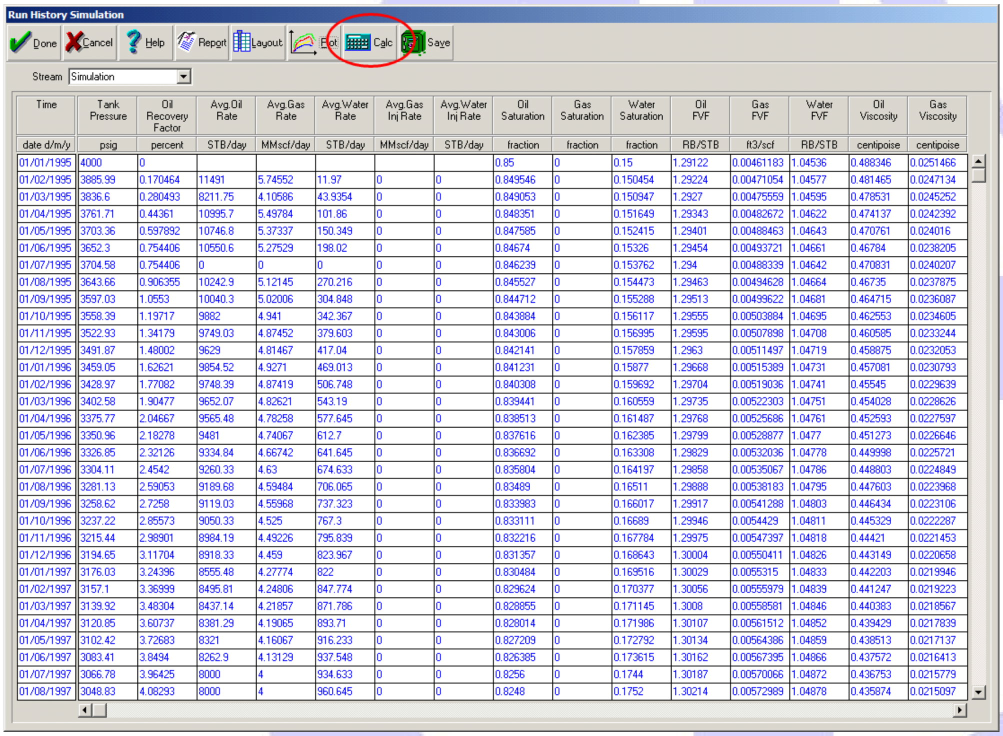
In forecast mode, the calculated variable is the reservoir pressure. This mimics the calculations done in simulation mode. Therefore the quality of the match and confidence in the forecast can be seen directly from the simulation plot. If the match here is good, then the forecast will more likely be OK as well.

To access the simulation, choose the **History Matching Simulation** menu:

CE



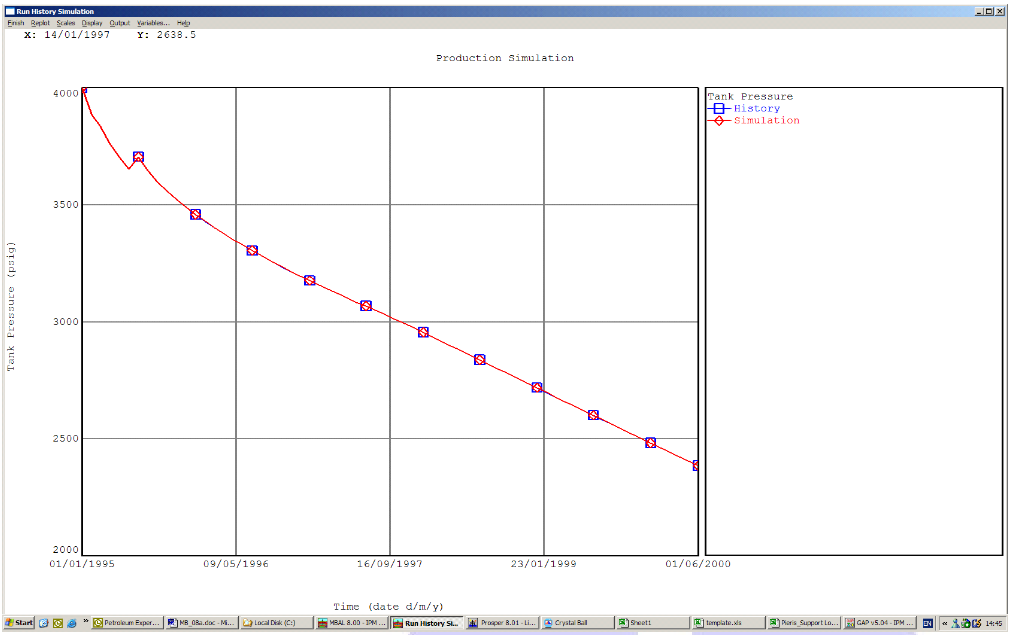
The following dialogue box is displayed:



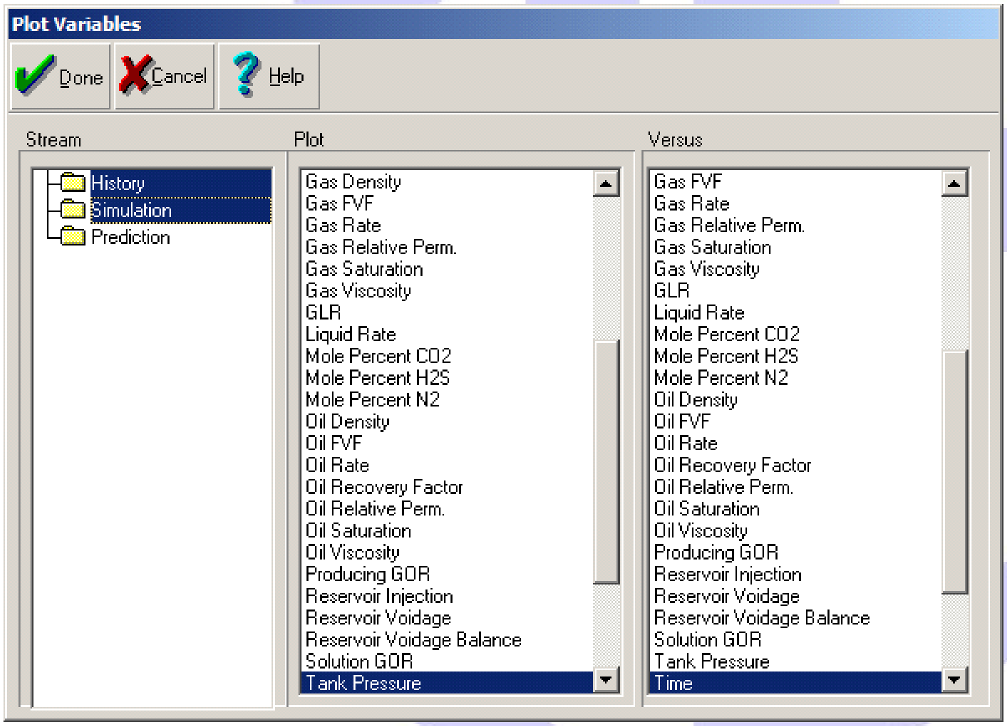
Stream Simulation

Time	Tank Pressure	Oil Recovery Factor	Avg.Oil Rate	Avg.Gas Rate	Avg.Water Rate	Avg.Gas Inj Rate	Avg.Water Inj Rate	Oil Saturation	Gas Saturation	Water Saturation	Oil FVF	Gas FVF	Water FVF	Oil Viscosity	Gas Viscosity
date d/m/y	psig	percent	STB/day	MMscf/day	STB/day	MMscf/day	STB/day	fraction	fraction	fraction	RB/STB	ft3/scf	RB/STB	centipoise	centipoise
01/01/1995	4000	0						0.85	0	0.15	1.29122	0.00461183	1.04536	0.488346	0.0251466
01/02/1995	3885.99	0.170464	11491	5.74552	11.97	0	0	0.849546	0	0.150454	1.29224	0.00471054	1.04577	0.481465	0.0247134
01/03/1995	3836.6	0.280493	8211.75	4.10586	43.9354	0	0	0.849053	0	0.150947	1.2927	0.00475559	1.04595	0.478531	0.0245252
01/04/1995	3761.71	0.44361	10995.7	5.49784	101.86	0	0	0.848351	0	0.151649	1.29343	0.00482672	1.04622	0.474137	0.0242392
01/05/1995	3703.36	0.597892	10746.8	5.37337	150.349	0	0	0.847585	0	0.152415	1.29401	0.00488463	1.04643	0.470761	0.024016
01/06/1995	3652.3	0.754406	10550.6	5.27529	198.02	0	0	0.84674	0	0.15326	1.29454	0.00493721	1.04661	0.46784	0.0238205
01/07/1995	3704.58	0.754406	0	0	0	0	0	0.846239	0	0.153762	1.294	0.00488339	1.04642	0.470831	0.0240207
01/08/1995	3643.66	0.906355	10242.9	5.12145	270.216	0	0	0.845527	0	0.154473	1.29463	0.00494628	1.04664	0.46735	0.0237875
01/09/1995	3597.03	1.0553	10040.3	5.02006	304.848	0	0	0.844712	0	0.155288	1.29513	0.00499622	1.04681	0.464715	0.0236087
01/10/1995	3558.39	1.19717	9882	4.941	342.367	0	0	0.843884	0	0.156117	1.29555	0.00503884	1.04695	0.462553	0.0234605
01/11/1995	3522.93	1.34179	9749.03	4.87452	379.603	0	0	0.843006	0	0.156995	1.29595	0.00507898	1.04708	0.460585	0.0233244
01/12/1995	3491.87	1.48002	9629	4.81467	417.04	0	0	0.842141	0	0.157859	1.2963	0.00511497	1.04719	0.458875	0.0232053
01/01/1996	3459.05	1.62621	9854.52	4.9271	469.013	0	0	0.841231	0	0.15877	1.29668	0.00515389	1.04731	0.457081	0.0230793
01/02/1996	3428.97	1.77082	9748.39	4.87419	506.748	0	0	0.840308	0	0.159692	1.29704	0.00519036	1.04741	0.45545	0.0229639
01/03/1996	3402.58	1.90477	9652.07	4.82621	543.19	0	0	0.839441	0	0.160559	1.29735	0.00522303	1.04751	0.454028	0.0228626
01/04/1996	3375.77	2.04667	9565.48	4.78258	577.645	0	0	0.838513	0	0.161487	1.29768	0.00525686	1.04761	0.452593	0.0227597
01/05/1996	3350.96	2.18278	9481	4.74067	612.7	0	0	0.837616	0	0.162385	1.29799	0.00528877	1.0477	0.451273	0.0226646
01/06/1996	3326.85	2.32126	9334.84	4.66742	641.645	0	0	0.836692	0	0.163308	1.29829	0.00532036	1.04778	0.449998	0.0225721
01/07/1996	3304.11	2.4542	9260.33	4.63	674.633	0	0	0.835804	0	0.164197	1.29858	0.00535067	1.04786	0.448803	0.0224849
01/08/1996	3281.13	2.59053	9189.68	4.59484	706.065	0	0	0.83489	0	0.16511	1.29888	0.00538183	1.04795	0.447603	0.0223968
01/09/1996	3258.62	2.7258	9119.03	4.55968	737.323	0	0	0.833983	0	0.166017	1.29917	0.00541288	1.04803	0.446434	0.0223106
01/10/1996	3237.22	2.85573	9050.33	4.525	767.3	0	0	0.833111	0	0.16689	1.29946	0.0054429	1.04811	0.445329	0.0222287
01/11/1996	3215.44	2.98901	8984.19	4.49226	795.839	0	0	0.832216	0	0.167784	1.29975	0.00547397	1.04818	0.44421	0.0221453
01/12/1996	3194.65	3.11704	8918.33	4.459	823.967	0	0	0.831357	0	0.168643	1.30004	0.00550411	1.04826	0.443149	0.0220658
01/01/1997	3176.03	3.24396	8555.48	4.27774	822	0	0	0.830484	0	0.169516	1.30029	0.0055315	1.04833	0.442203	0.0219946
01/02/1997	3157.1	3.36999	8495.81	4.24806	847.774	0	0	0.829624	0	0.170377	1.30056	0.00555979	1.04839	0.441247	0.0219223
01/03/1997	3139.92	3.48304	8437.14	4.21857	871.786	0	0	0.828855	0	0.171145	1.3008	0.00558581	1.04846	0.440383	0.0218567
01/04/1997	3120.85	3.60737	8381.29	4.19065	893.71	0	0	0.828014	0	0.171986	1.30107	0.00561512	1.04852	0.439429	0.0217839
01/05/1997	3102.42	3.72683	8321	4.16067	916.233	0	0	0.827209	0	0.172792	1.30134	0.00564386	1.04859	0.438513	0.0217137
01/06/1997	3083.41	3.8494	8262.9	4.13129	937.548	0	0	0.826385	0	0.173615	1.30162	0.00567395	1.04866	0.437572	0.0216413
01/07/1997	3066.78	3.96425	8000	4	934.633	0	0	0.8256	0	0.1744	1.30187	0.00570066	1.04872	0.436753	0.0215779
01/08/1997	3048.83	4.08293	8000	4	960.645	0	0	0.8248	0	0.1752	1.30214	0.00572989	1.04878	0.435874	0.0215097

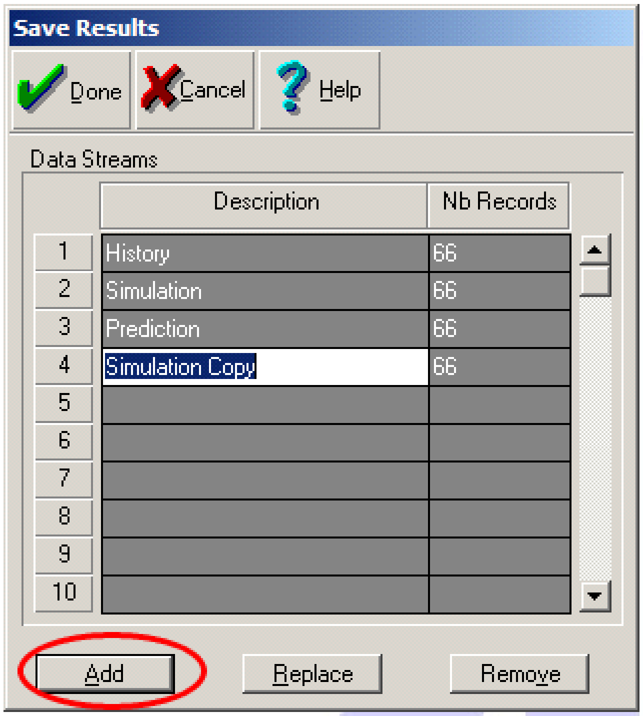
Calculations can be run by selecting the “Calc” button, followed by the “Plot” button in order to look at the comparison between calculated pressures and historical pressures:


Run History Simulation
Finish Replot Scales Display Output Variables... Help
X: 14/01/1997 Y: 2638.5
Production Simulation
Tank Pressure (psig)
4000
3500
3000
2500
2000
01/01/1995
09/05/1996
16/09/1997
23/01/1999
01/06/2000
Time (date d/m/y)
Tank Pressure
History
Simulation

Under the “Variables” option on the plot, different variables or streams can be chosen for plotting. Please ensure that both the 'Simulation' and 'History' streams are selected when comparing the two.


Plot Variables
Done
Cancel
Help
Stream
History
Simulation
Prediction
Plot
Gas Density
Gas FVF
Gas Rate
Gas Relative Perm.
Gas Saturation
Gas Viscosity
GLR
Liquid Rate
Mole Percent CO2
Mole Percent H2S
Mole Percent N2
Oil Density
Oil FVF
Oil Rate
Oil Recovery Factor
Oil Relative Perm.
Oil Saturation
Oil Viscosity
Producing GOR
Reservoir Injection
Reservoir Voidage
Reservoir Voidage Balance
Solution GOR
Tank Pressure
Versus
Gas FVF
Gas Rate
Gas Relative Perm.
Gas Saturation
Gas Viscosity
GLR
Liquid Rate
Mole Percent CO2
Mole Percent H2S
Mole Percent N2
Oil Density
Oil FVF
Oil Rate
Oil Recovery Factor
Oil Relative Perm.
Oil Saturation
Oil Viscosity
Producing GOR
Reservoir Injection
Reservoir Voidage
Reservoir Voidage Balance
Solution GOR
Tank Pressure
Time

Selecting the “Save” button from the calculation menu allows saving different runs, which will then appear as separate stream in the “Variables” screen shown above.



	Description	Nb Records
1	History	66
2	Simulation	66
3	Prediction	66
4	Simulation Copy	66
5		
6		
7		
8		
9		
10		

Create a new stream by clicking the “Add” button highlighted above.

2.4.5.7 Fw / Fg / Fo Matching

One of the main difficulties when running a 'Production Prediction' is to find a set of relative permeability curves which will result in a GOR, WC or WGR similar to those observed during the production history. The purpose behind this tool is to generate a set of Corey function parameters that will reproduce the fractional flows observed in the production history.

The relative permeabilities can be generated for the; tank, individual wells or transmissibilities.

- In order to generate the relative permeabilities for a well, the production history for this well must be entered in the **Well Data Input** section.
- In order to generate the relative permeabilities for a transmissibility, the production history for it must be entered in the ‘Transmissibility Data’ Input section and the 'Use Production History' flag will need to be switched on. Note that the history simulation has to be run after this input data has been entered. If this is not done, the history simulation uses the rel perms of the source tank so any Fw/Fg/Fo match will simply generate the entered relative permeability curves. In order for the transmissibility relative permeabilities to be used in the prediction, the 'Use Own' option must be set

in the ' Transmissibility Data' Input section after performing the Fw/Fg/Fo match.

Choose the item to regress on by selecting the tank, transmissibility or the well in the item menu option.

In a Corey function, the relative permeability for the phase x is expressed as:

$$Krx = Ex * \left(\frac{Sx - Srx}{Smx - Srx} \right)^{nx}$$

where :
Ex is the end point for the phase x,
nx the Corey Exponent,
Sx the phase saturation,
Srx the phase residual saturation and
Smx the phase maximum saturation.

The phase absolute permeability can then be expressed as:

$$Kx = K * Krx$$

where :
K is the reservoir absolute permeability and
Krx the relative permeability of phase x.

For the purpose of clarity, the following detailed explanation describes the matching of the water fractional flow in an oil tank.

The first step is to calculate the points from the input production history which are shown as points on the plot. For each production history point the Sw value is the one calculated in the production history. The Fw value is calculated using the rates from the production history and the PVT properties. Now accounting for the capillary pressures and the gravities, the water fractional flow can be expressed as:

$$Fw = \frac{Qw * Bw}{Qo * Bo + Qw * Bw}$$

where :
Qx the flow rate and
Bx the Formation volume factor of phase x.

The second step is to calculate the theoretical values – these are displayed as the solid line on the plot. As for the date points, the water saturations are taken from simulation. The Fw is calculated from the PVT properties and the current relative permeability curves using:

$$Fw = \frac{\frac{Kw}{\mu w}}{\frac{Kw}{\mu w} + \frac{Ko}{\mu o}}$$

When a regression is performed, the Corey terms are adjusted with respect to the relative permeability curves to best match the Fw from the data points and the Fw from the theoretical curves.

The other matching types are defined as follows:

- For Fg matching in an oil tank, Fg is the gas rate divided by the sum of the gas, oil and water rates. Note that the gas rate is the free gas produced from the tank – not the gas produced at surface.
- For Fw matching in a gas tank, Fw is the water rate divided by the sum of the water and gas rate.
- For Fw matching in a condensate tank, Fw is the water rate divided by the sum of the water and gas rate.
- For Fo matching in a condensate tank, Fo is the oil rate divided by the sum of the gas plus oil rate. Note that the oil rate is the free oil produced from the tank – not the oil produced at surface.

➡ This fractional flow matching tool can only be used if a simulation has been run. It is also important to re-run a simulation each time input parameters are changed as they will probability affect the saturations and/or the PVT properties.

A plot showing the fractional flow versus saturation will be displayed. No data points will be displayed if :

- the simulation has not been run,
- there is no water/gas production.

Most of the time, particularly after a long production history, the late WC do not really represent the original fractional flows. They usually take into account the water breakthroughs and also show the different work-overs done to reduce water production.

These late data point can be hidden from the regression by double clicking on the point to remove. A group of points can also be removed by drawing a rectangle around these points using the right mouse button. The data points weighting in the regression can also be changed using the same technique. Refer to Weighting of Regression Points for more information.

The breakthrough for the saturation that is displayed on the X axis is marked on the plot by a vertical green line. This will be taken into account by the regression. The breakthrough value can be changed on the plot by simply double-clicking on the new position - the breakthrough should be redrawn at the new position.

Click on **Regression** to start the calculation. The program will display a set of Corey function parameters that best fits the input data.

➡ These parameters represent the best mathematical fit for the input data, insuring a continuity in the WC, GOR and WGR between history and forecast. This set of Corey function parameters will make sure that the fractional flow equations used in the 'Production Prediction' tool will reproduce as close as possible the fractional flow observed during the history

These parameters have to be considered as a group and the individual value of each parameter does not have a real meaning as, most of the time, the solution is not unique.

The set of parameters can be edited by selecting Parameters option from the plot menu.

This set of regressed parameters can be copied into the Production Prediction data set by selecting the **Save** option from the plot menu.

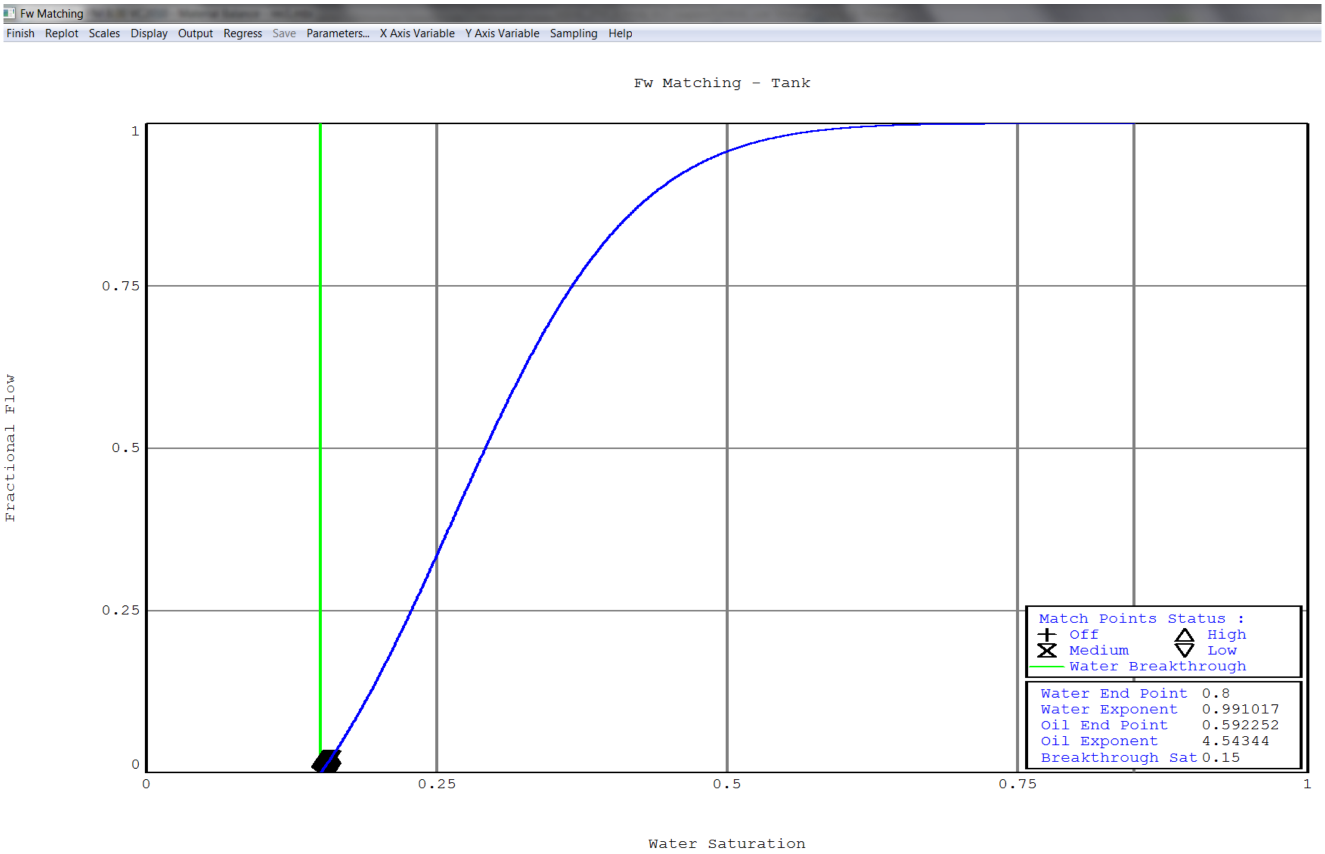
➡ In the case of an oil reservoir, the water fractional flow should be matched before the gas fractional flow

2.4.5.7.1 Running a Fractional Flow Matching

Having entered the necessary data, a regression can be carried out on the fractional flow of each phase upon which prediction calculations will be based.

The plot shown for fractional flow matching displays 'Saturation' along the x-axis and 'Fractional Flow' along the y-axis. This regression will define the relative permeabilities for each phase for forecast calculations and is carried out using the same method as was originally defined.

Selecting **History Matching|Fw Matching** a plot showing the fractional flow versus saturation will be displayed:


Fw Matching
Finish
Replot
Scales
Display
Output
Regress
Save
Parameters...
X Axis Variable
Y Axis Variable
Sampling
Help
Fw Matching - Tank
Fractional Flow
Water Saturation
0
0.25
0.5
0.75
1
Match Points Status :
Off
High
Medium
Low
Water Breakthrough

Water End Point 0.8
Water Exponent 0.991017
Oil End Point 0.592252
Oil Exponent 4.54344
Breakthrough Sat 0.15

No data points will be displayed if:

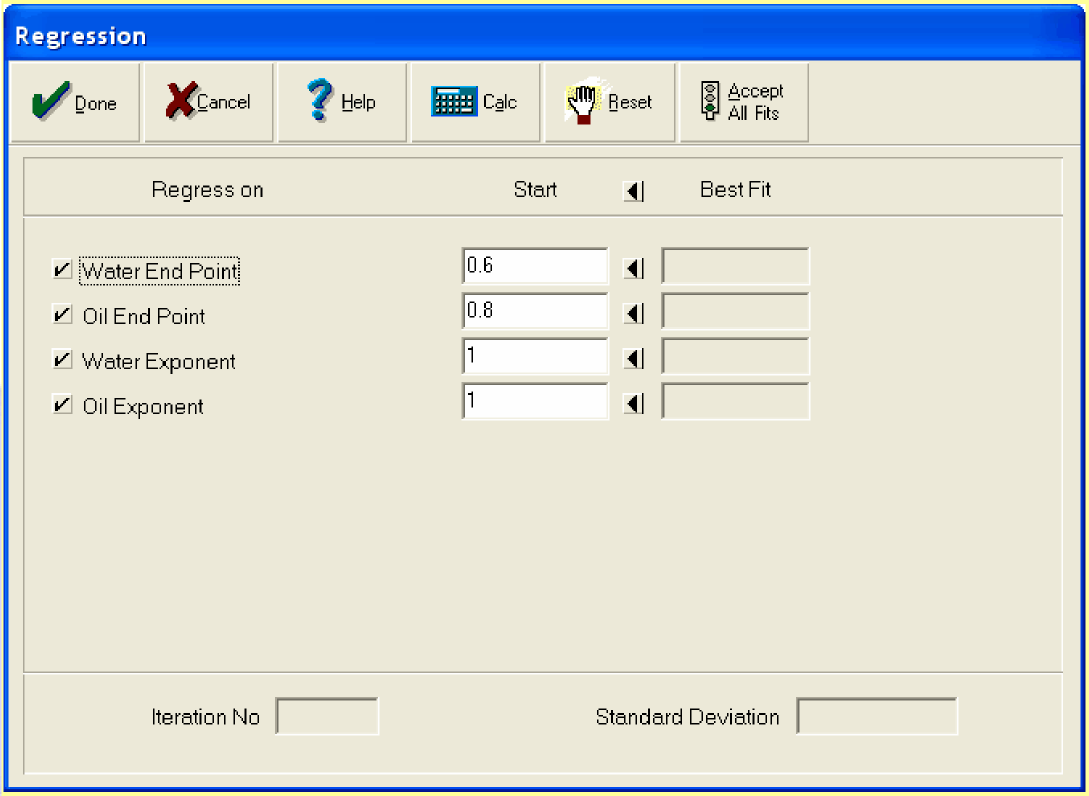
- the simulation has not been run,
- There is no production of the phases required for the match.

After a long production history, the late WC will not necessarily represent the original fractional flows, these values will usually account for the water breakthroughs, and also reflect the different workovers required to reduce water production.
These late data points can be hidden from the regression by double-clicking on the point to remove. A group of points can also be removed by drawing a rectangle around these points using the right mouse button. The data points weighting in the regression can also be changed using the same technique. (Refer to the 'Changing the Weighting of History Points in the Regression' section described above.)

The breakthrough for the saturation is displayed on the X axis and is marked on the plot by a vertical green line. This will be taken into account during the regression. The breakthrough value can be changed on the plot by simply double-clicking on the new position – the breakthrough should be redrawn at the new position.

Click on **Regression** to start the calculation and after a few seconds, the program will display a set of Corey function parameters that best fit the input data.

Regress on default	(recommended) Traditionally, the regression was carried out on default variables: water end

variables	point, oil end point, water exponent and oil exponent. The regression is carried out on all of these to ensure that a plot is obtained which matches the historical data. Water end point and water exponent and these have been found to be the most effective for the majority of systems. Having obtained a plot which follows the historical saturation Vs fractional flow allows the relative permeabilities for each phase to be defined.
Regress on selected variables	The user can decide from the four variables which should be regressed upon, therefore defining which variables are to be altered to ensure that the plotted fractional flow is observed.  Regression Done Cancel Help Calc Reset Accept All Fits Regress on — Start — Best Fit ☑ Water End Point 0.6 ☑ Oil End Point 0.8 ☑ Water Exponent 1 ☑ Oil Exponent 1 Iteration No Standard Deviation The desired variables upon which the regression is to be carried out can be selected and the 'Calc' button clicked on. To ensure that these results are carried through into the tank model, 'Accept All Fits' should be selected.

By default, the first screen to be shown applies to the tank. Selecting the regress button will allow the choice of parameters upon which the regression is to be carried out to be defined.

If more than one well is present in the model, a regression will need to be carried out for each them to determine the fractional flow and resulting relative permeabilities for each phase (this is done by selecting the menu'Well'). This means that prediction calculations for each well will now be calculated while accounting for the fractional flow of phases into them

➡ **These parameters represent the best mathematical fit for the data, insuring continuity in the WC, GOR and WGR between history and forecast. This set of Corey function parameters will make sure that the fractional flow equations used in the 'Production Prediction' tool will reproduce as close as possible the fractional flow observed during the history. These parameters have to be considered as a group and the individual value of each parameter does not have a real meaning as, most of the time, the solution is not unique.**

The set of parameters can be edited by selecting **Parameters** option from the plot menu.

The set of parameters regressed can be copied permanently into the data set by selecting the **Save** option from the plot menu.

➡ **In the case of an oil reservoir, the water fractional flow should be matched before the gas fractional flow.**

New in IPM 8.0

More variables are available in tge fractional flow matching screen as can be seen on the above screen shot (i.e. x-axis and y-axis menus)

2.4.5.8 Sensitivity Analysis

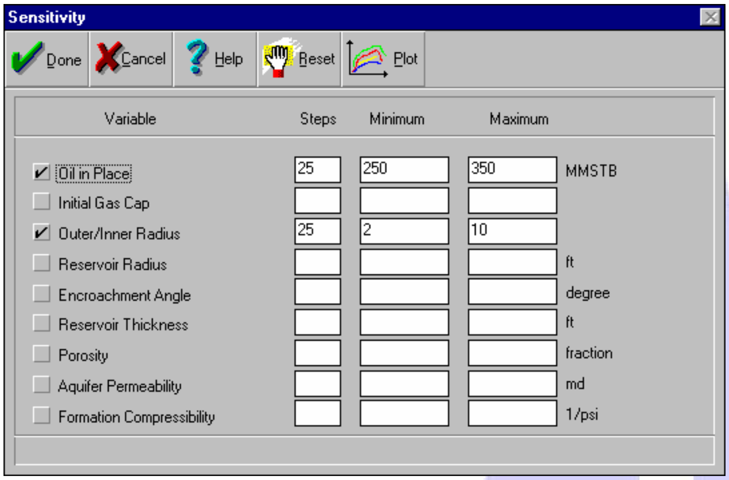
This option is used for running sensitivity on one or two variables at a time. A certain number of values between a minimum and a maximum can be defined for each variable. For each combination of values the program will calculate the standard deviation of the error on the material balance equation rewritten:

$$(F - We)/(N*E) - 1 = 0$$

For oil the regression uses the point selected in the analytical method along with the respective weightings.

It should be noted that this option is not available for multi-tank cases.

To access this option and view the screen below; **History Matching | Sensitivity menu** should be selected:



	Variable	Steps	Minimum	Maximum	
☑	Oil in Place	25	250	350	MMSTB
☐	Initial Gas Cap				
☑	Outer/Inner Radius	25	2	10	
☐	Reservoir Radius				ft
☐	Encroachment Angle				degree
☐	Reservoir Thickness				ft
☐	Porosity				fraction
☐	Aquifer Permeability				md
☐	Formation Compressibility				1/psi

2.4.5.8.1 Running a Sensitivity

Select the sensitivity variables by checking the corresponding boxes and specify the number of steps the program is to perform between the minimum and maximum values. Selecting 20 steps will generate 21 values for the variable from the minimum to the maximum. Selecting 20 steps for each variable will perform (20+1)*(20+1) runs. If necessary, these values can be reset by clicking the **Reset** command button.

Click **Plot** to start the calculation. After a few seconds, a plot of one of the variables versus the standard deviation will appear. A sharp minimum indicates the most probable value for this variable. A flat minimum indicates a range of probable values. Select **Variables** to change the variable being plotted.

When two variables are used, the plotting of the standard deviation will also indicate the uniqueness of the solution. In some cases, the program will show that for each value of the first parameter, there exists a value for the second parameter that gives the same minimum standard deviation. This means there is an infinite number of solutions and that one of the variables must be fixed in order to calculate the other.

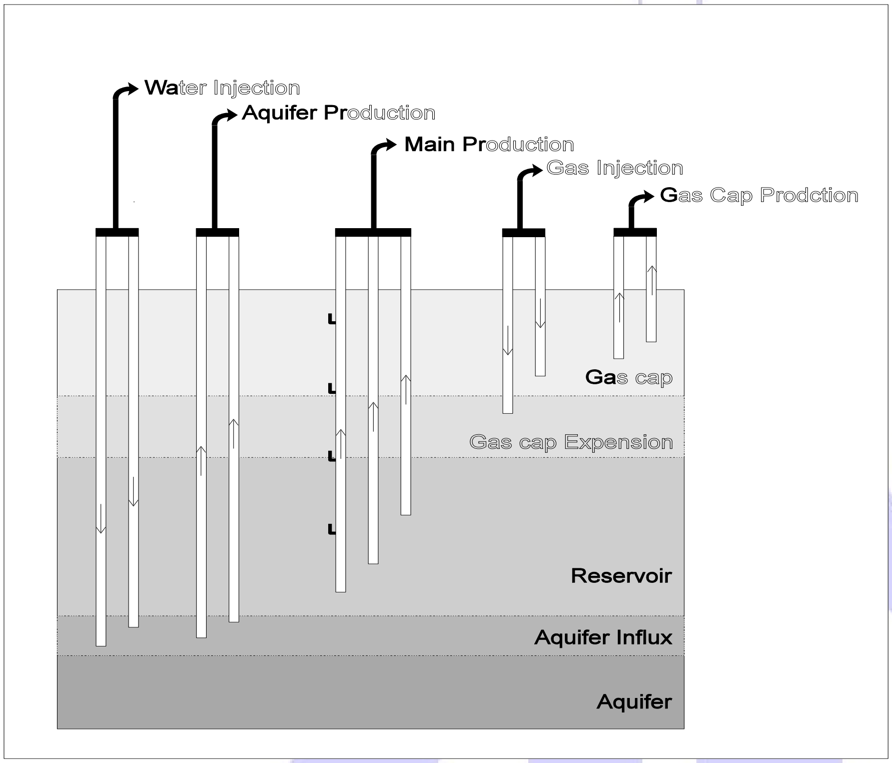
2.4.6 Production Prediction

The production prediction section of the program is used to forecast the reservoir performance. The program can switch from history simulation to prediction mode at a date selected by the user.

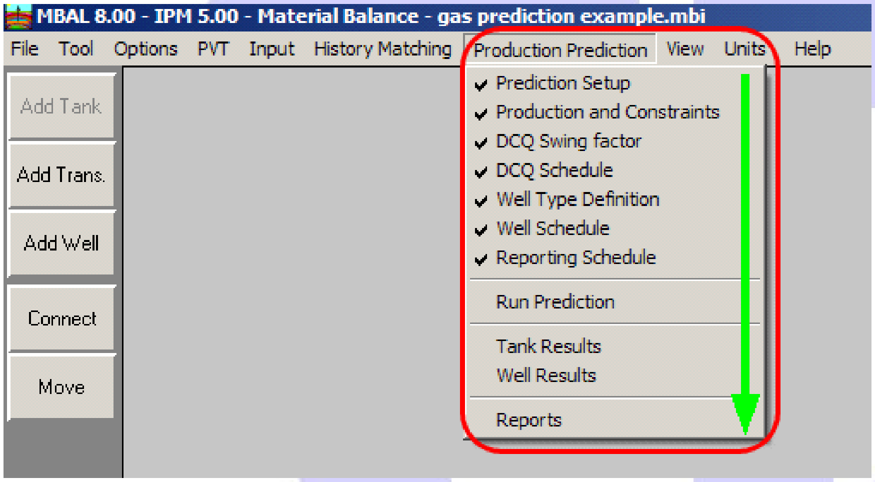
The model assumes the following:

- All of the producers are connected to the same production manifold.
- All of the water injectors are connected to the same water injection manifold.
- All of the gas injectors are connected to the same gas injection manifold.
- All of the aquifer producers are connected to the same aquifer production manifold.
- All of the gas cap producers are connected to the same gas cap production manifold.

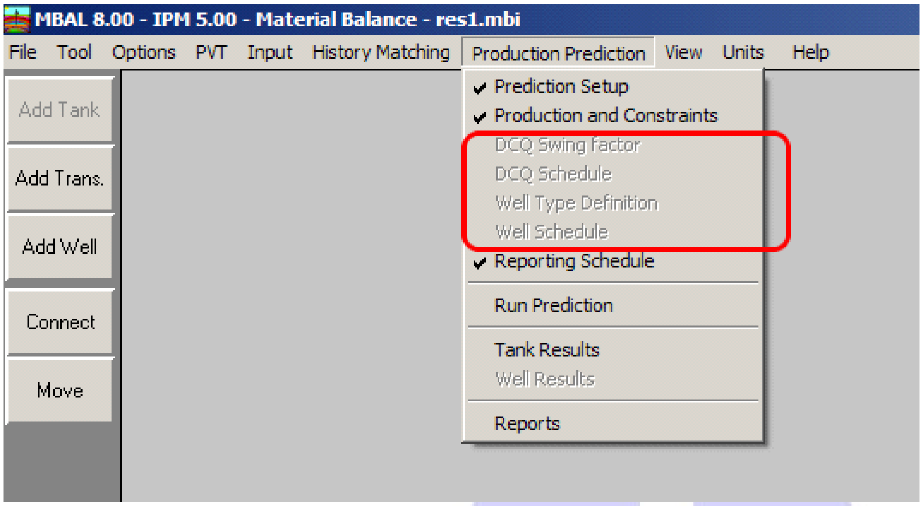
- The pressure of the five manifolds can be set independently.


Water Injection
Aquifer Production
Main Production
Gas Injection
Gas Cap Prodction
Gas cap
Gas cap Expension
Reservoir
Aquifer Influx
Aquifer

The program provides different types of prediction depending on the fluid chosen. Performing a forecast involves following the 'Production Prediction' menu from top to bottom:


MBAL 8.00 - IPM 5.00 - Material Balance - gas prediction example.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Add Tank
Add Trans.
Add Well
Connect
Move
✓ Prediction Setup
✓ Production and Constraints
✓ DCQ Swing factor
✓ DCQ Schedule
✓ Well Type Definition
✓ Well Schedule
✓ Reporting Schedule
Run Prediction
Tank Results
Well Results
Reports

The screen above shows all of the active options, if some are not relevant to the model they will be automatically greyed out as shown below:


MBAL 8.00 - IPM 5.00 - Material Balance - res1.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Add Tank
Add Trans.
Add Well
Connect
Move
✓ Prediction Setup
✓ Production and Constraints
DCQ Swing Factor
DCQ Schedule
Well Type Definition
Well Schedule
✓ Reporting Schedule
Run Prediction
Tank Results
Well Results
Reports

The various options on performing forecasts are best explained through examples. Please refer to the "Quick Start Guide 512" example for information on performing forecasts with and without wells. The sections below will therefore only provide limited information on the forecast screens.

2.4.6.1 Production Prediction Overview

The production prediction section of the program is used to simulate the reservoir performances. The program can switch from history simulation to prediction mode at a date selected by the user.

The model assumes the following:

- All the producers are connected to the same production manifold.
- All the water injectors are connected to the same water injection manifold.
- All the gas injectors are connected to the same gas injection manifold.
- All the aquifer producers are connected to the same aquifer production manifold.
- All the gas cap producers are connected to the same gas cap production manifold.
- The pressure of the five manifolds can be set independently.

The program provides 4 different types of predictions:

Reservoir Pressure only from Production Schedule	Use this option to find reservoir pressures for a given production off take. This is the classical material balance calculation. In this mode the well and manifold are completely ignored. Only the tank and the aquifer are taken into account. The user enters the tank production and injection schedule. The program simulates the tank and aquifer behaviours.

Input data	• The tank parameters and relative permeabilities • The aquifer type and parameters • The description of the fluids injected (optional) • The production schedule for the main phase (e.g. c gas for a gas or condensate system). • The injection schedule (optional)
Assumptions	The GOR, CGR, WC, WGR, etc. are calculated from using the tank relative permeabilities. These values t other phase rates (e.g. water rate for an oil system). also be entered to correct the tank relative permeabi notion of abandonment
Calculated data	• The tank pressure and saturations, • Tank rates and cumulative productions for the othe • Tank average water salinity, gas cap gravity, etc

➲ This mode is not available with multiple tanks

Reservoir Pressure and Production from Manifold Pressure

Use this option to calculate production forecasts for a given reservoir and well configuration

In this mode the user has to enter the manifold pressure schedules. The program uses the well definitions (IPRs, TPC's) to evaluate the performance of each well for given reservoir and manifold pressures. The program iterates on the manifold pressures until the total production and injections match the schedule provided.

Additionally, minimum and maximum constraints can be set on the production and injection rates. When triggered, these constraints supersede the manifold pressure schedules. For example, if the production manifold pressure specified by the user triggers the maximum production rate, the program will increase the manifold pressure to satisfy this constraint, overriding the user input. This facility can be used for example to define a production plateau followed by a decline.

Input data	• The tank parameters and relative permeabilities • The aquifer type and parameters • The well performance definitions, including IPRs ar Performance Curves • The constraints on injection and production rates • The manifold pressures schedules • The well (or drilling) schedule

<table>
<tr>
<td></td>
<td>
<table>
<tr><td>Assumptions</td><td>The GOR, CGR, WC, WGR, etc. are still calculated f
flows using the reservoir relative permeabilities but b
abandonment, and/or production constraints can be
well definitions</td></tr>
<tr><td>Calculated data</td><td>• The tank pressure and saturations,
• Tank rates and cumulative productions for the all p
• Tank average salinity, impurity constraints, etc.
• Manifold pressures (if constraint is triggered),
• Individual well performances such as :
• Production or injection rates,
• Flowing bottom hole pressure,
• Flowing or manifold pressure (if rate constraint trig
• CGR, GOR, WC, WGR, etc.</td></tr>
</table>
</td>
</tr>
<tr>
<td>DCQ from Swing Factor and DCQ Schedule</td>
<td>
(Gas Reservoirs Only)
Use this option to determine the contract rate a given reservoir and well configuration can support.

In this mode the program calculates the maximum daily gas contract that the reservoir can deliver over the specified periods of time. The program takes into account a seasonal swing factor entered in the ‘DCQ Swing Factor’ Table (see below), and a maximum swing factor entered in the ‘DCQ Schedule’ Table (see below). The program also honours (where possible) the constraints entered in the ‘Production and Constraints’ table. If well definitions and well schedules are provided, the program calculates the production manifold pressure (or compressor back pressure) required to meet the DCQ.
<table>
<tr><td>Input data</td><td>• The reservoir parameters and relative permeabiliti
• The aquifer type and parameters,
• The well and reservoir performance definitions, inc
Tubing Performance Curves.
• The manifold pressures schedules,
• The constraints on injection and production rates,
• The well (or drilling) schedule,
• DCQ swing factors describe the seasonal variatio
year basis,
• DCQ schedule describing the dates at which a ne
along with the maximum swing factor</td></tr>
<tr><td>Assumptions</td><td>The WGR is still calculated from the fractional flows u
relative permeabilities but, breakthrough, abandonm
production constraints can be provided with the well</td></tr>
<tr><td>Calculated</td><td>• The tank pressure and saturations
• DCQ, tank rates and cumulative productions for all</td></tr>
</table>
</td>
</tr>
</table>

<table>
<tr>
<td></td>
<td>
<table>
<tr>
<td>data</td>
<td>• Tank average salinity, impurity constraints, etc.
• Manifold pressures (if rate constraints are triggere
• Individual well performances such as :
• Production or injection rates,
• Flowing Bottom hole pressure,
• Flowing or manifold pressure (if rate constraints ar
• CGR, WGR, etc.</td>
</tr>
</table>
</td>
</tr>
<tr>
<td>Calculate Minimum Number of Wells to achieve Target Rate</td>
<td>This mode is based on the 2nd prediction type 'Reservoir Pressure and Production from Manifold Pressure'. It includes additional logic to allow calculation of the number of wells required to achieve a target rate.
The input data is the same as 'Reservoir Pressure and Production from Manifold Pressure' with the following additions:
• In the 'Production and Constraints', enter the target rate schedule.
• The potential well schedule. This is a list of potential wells that the program can drill to achieve the target rate if existing wells do not have sufficient productivity.
Once wells have been drilled they remain in production.
A drilling time can be entered for the potential wells. If entered, new potential wells can not be drilled until the drilling time has passed</td>
</tr>
</table>

The program can be used in prediction mode only. Where this may be the case, the Production History part of the **Input Tanks Data** section and the **History Matching** section can be completely ignored.

Reservoir Simulation Calculation Technique

At each time step MBAL does the following :

Calculation Steps	1. Assumes a tank average pressure, 2. Calculates the relative permeabilities and fractional flow of the 3 phases , 3. Calculates the produced GOR/CGR and WOR/WGR. 4. Calculates the individual well production or injection rates and flowing pressures based on: • the fluids PVT, • the IPR, • the tubing performance curve or constant bottom hole pressure, • the production/injection constraints, • the production schedule, 5. Calculates the water influx for this reservoir pressure and time

	6. Calculates the tank overall productions and injections, 7. For multi-tanks, calculates the transmissibility rates, 8. Calculates the gravity of the gas and water phases, 9. Calculates the tank's new saturations and assumes a new reservoir pressure, 10. Iterates until convergence of tank pressure.
Calculated Properties	During the simulation, the program will always calculate the following properties : • Tank average pressure, • Oil, gas and water saturations, • Oil, gas and water relative permeabilities based on the saturations, • PVT properties of the three phases, • Water and gas fractional flows based on relative permeabilities, dip angle and PVT, • Gas cap average gravity, taking into account the gravity of the gas injected and out of solution (oil reservoir only), • The gas impurity constraints (for gas storage only), taking into account the H_2S, CO_2 and N_2 constraints of the gas in place and the gas injected. • The water average salinity, taking into account the salinity of the water injected (oil reservoir only)
Calculation and Reporting Time Steps	The *Reporting Frequency* (or time step - see Reporting Schedule) can be set by the user to determine the times displayed in the results dialogues. However there are usually extra calculation times between the time steps displayed on the results dialogues or reports. • The prediction step size defaults to 15 days. This can be changed in the Prediction Setup dialogue. Extra calculation times will be inserted based on the prediction step size. • Changes in production and constraints. An extra calculation time will be inserted whenever there is a change in any of the entries in the Prediction Production and Constraints dialogue. • A calculation time will be inserted if and when the calculation changes from history to prediction mode. • A calculation time will be inserted whenever a well is started or shut in as defined in the Well Schedule dialogue. • A calculation time will be inserted whenever there is a change in any of the DCQ inputs **Switching Between History Simulation and Prediction** To run an accurate prediction, the calculation should always be started from day one of the reservoir producing live. This can be time consuming if a run has been selected upon which the prediction based on the well performance definitions. This would require: - the entry of the performance definition of all the wells that have been

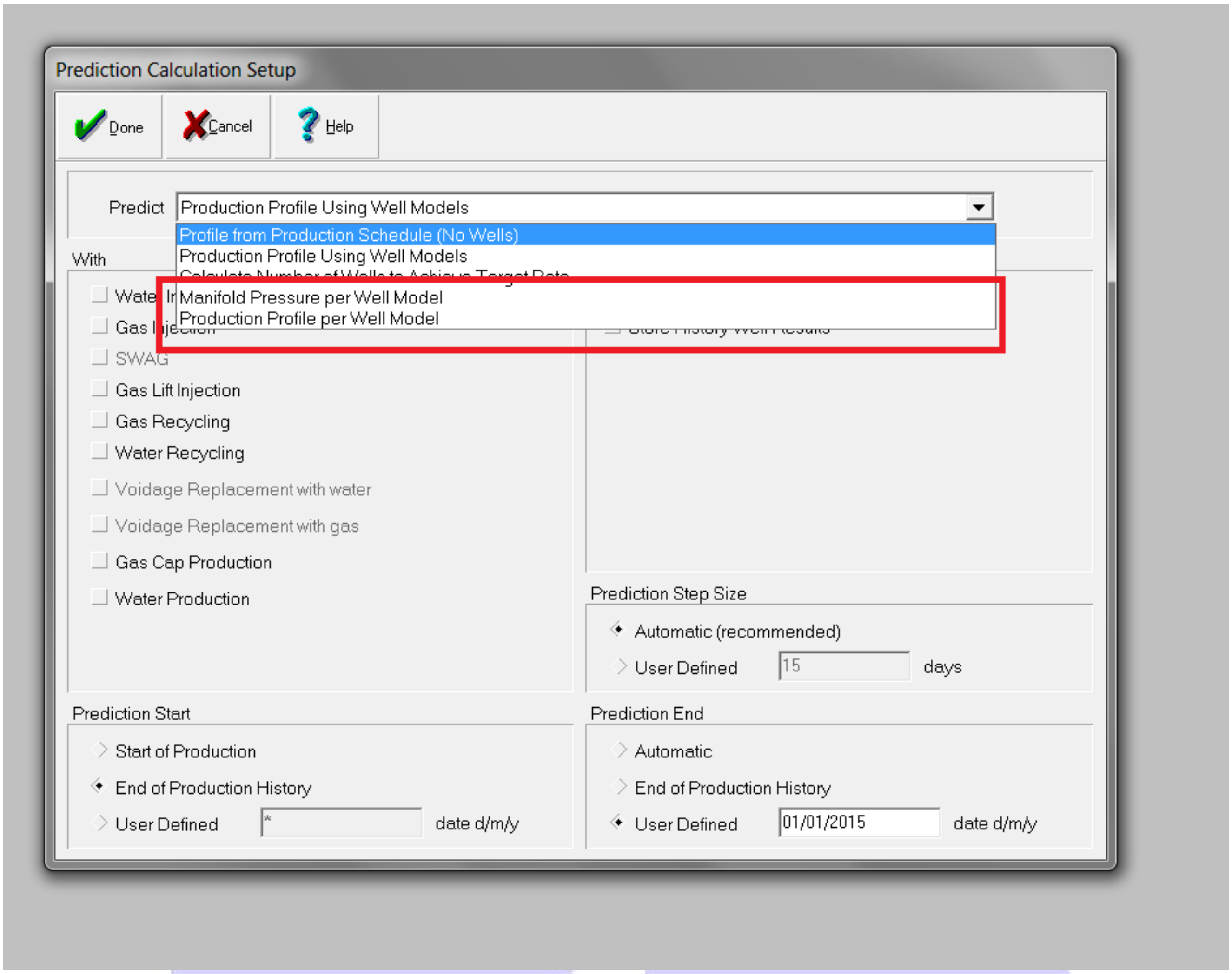
	active since the reservoir started production, - along with their evolution in time (change of completion, stimulation, change of well head conditions, etc.). For this the reason the program offers the possibility of running the simulation based on the Production History from day 1 to a user defined date - this will do exactly the same calculation as the simulation in History Matching. Prediction Mode can then be switched to, to use the well performance definitions provided. The variable ‘switching’ date provides the user with the possibility of an overlap in the last part of the production history, allowing a check the on the validity of the well performance definitions provided. It also avoids duplicating the entry of the production history if the prediction was based on a production schedule. The ‘switching’ date can be set anywhere between day one and the last day of the production history. See Prediction Setup for more details

2.4.6.2 Prediction Setup

Following the options from top to bottom, the first screen to be accessed is the 'Prediction setup'.

This is the first prediction dialogue box. It defines the type of prediction to be performed, the start and end of prediction and the reporting frequency.

In this, the mode of forecasting should first be selected.


Prediction Calculation Setup
Done
Cancel
Help
Profile from Production Schedule (No Wells)
Production Profile Using Well Models
Calculate Number of Wells to Achieve Target Rate
Manifold Pressure per Well Model
Production Profile per Well Model
With
☐ Water Injection
☐ Gas Injection
☐ SWAG
☐ Gas Lift Injection
☐ Gas Recycling
☐ Water Recycling
☐ Voidage Replacement with water
☐ Voidage Replacement with gas
☐ Gas Cap Production
☐ Water Production
☐ Store History Well Results
Prediction Step Size
○ User Defined
days
Prediction Start
○ Start of Production
○ User Defined
date d/m/y
Prediction End
○ Automatic
○ End of Production History
date d/m/y

Predict: Production Profile Using Well Models

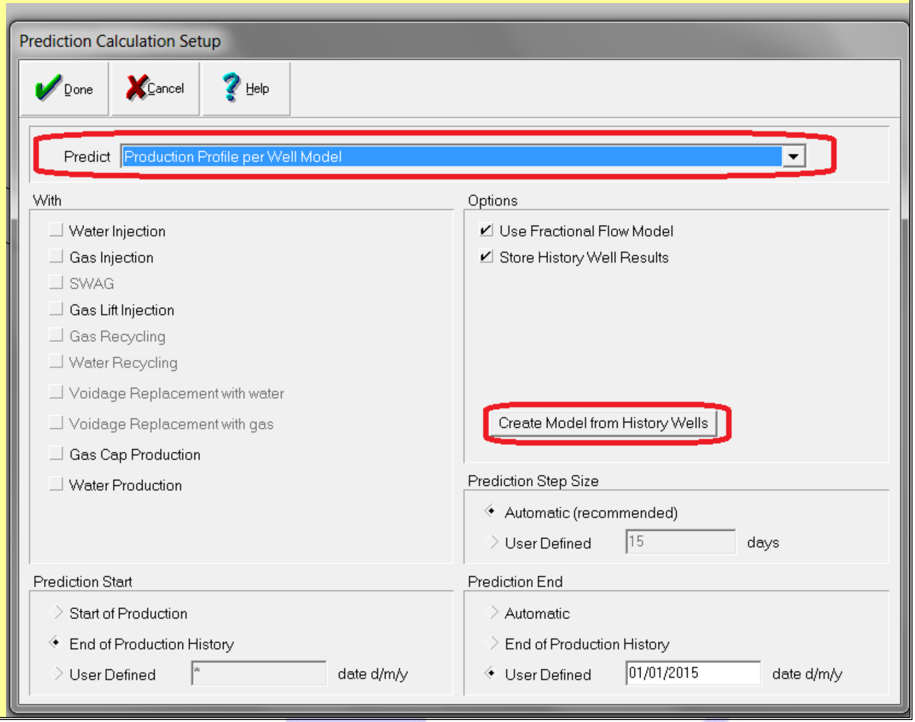
Prediction Step Size: ● Automatic (recommended); User Defined 15 days

Prediction Start: ● End of Production History

Prediction End: ● User Defined 01/01/2015 date d/m/y

In the case of an **Oil System**, there are three prediction options available:

Profile from Production Schedule (No Wells)	This mode consists of predicting the reservoir pressure based on a production schedule entered by the user
Production Profile Using Well Models	This mode consists of predicting the production profile and reservoir pressure based on the well performance entered for each well present in the system
Calculate Number of Wells to Achieve Target Rate	This model allows to determine the number of wells (template) that are required to be drilled in order to achieve a certain production schedule
Manifold pressure per well model	***New in IPM8.0*** This option allows the WHP for each well to be specified for the prediction period.

	Navigating to ***Production Prediction| Well type definition*** the manifold pressure per well (and any other constraints) can be applied.
Production profile per well model	***New in IPM8.0*** This option allows the user to specify oil rate (in the history and prediction period) and **MBAL** will calculate the reservoir response. This can be used to quality check that the Rel Perms from regression are consistent with historical production data. Using this option allows the user to create prediction wells from the history well.  Prediction Calculation Setup Predict: Production Profile per Well Model With: ☐ Water Injection ☐ Gas Injection ☐ SWAG ☐ Gas Lift Injection ☐ Gas Recycling ☐ Water Recycling ☐ Voidage Replacement with water ☐ Voidage Replacement with gas ☐ Gas Cap Production ☐ Water Production Options: ☑ Use Fractional Flow Model ☑ Store History Well Results Prediction Step Size: ● Automatic (recommended) ○ User Defined 15 days Prediction Start: ○ Start of Production ● End of Production History ○ User Defined * date d/m/y Prediction End: ○ Automatic ○ End of Production History ● User Defined 01/01/2015 date d/m/y

whereas for a **Gas System**, there are four options available for the prediction:

Profile from Production Schedule (No Wells)	This mode consists of predicting the reservoir pressure based on a production schedule entered by the user
Production Profile Using Well Models	This mode consists of predicting the production profile and reservoir pressure based on the well performance entered for each well present in the system
Calculate Number of Wells to Achieve Target	This model allows to determine the number of wells (template) that are required to be drilled in order to achieve a certain production

Rate	schedule
DCQ Using Well Models and Swing Factors	This mode calculates the DCQ that can be achieved by the system, taking into account of a give seasonal variation of demand (defined by Swing factors)

Input Fields

<table>
<tr><td>Predict</td><td>Defines one of the three prediction types described in Prediction Overview</td></tr>
<tr><td>With</td><td>Defines the different type of injections/productions etc. The main purpose of these options is to simplify the following data entry screens. For example, if the 'Water Injection' box is not checked, no water injection fields will be displayed in the rest of the prediction screens.
Please note the special functionality associated with use of Voidage Replacement and Injection 281.
If 'General' material balance is in use, then it is possible to model oil leg producers and gas cap producers. If both of these options are selected, a common manifold for both oil leg and gas cap producers could be defined. Otherwise a separate manifold for oil leg and gas cap producers will be used</td></tr>
<tr><td>Prediction
Start</td><td>Defines when the program will switch from 'History Simulation' to 'Prediction'.
<table>
<tr><td>Start of Production</td><td>Prediction starts on the first day of production of the tank (specified in Tank Parameters). For multi-tank systems, if the tanks have different times for the start of production, it will use the earliest one</td></tr>
<tr><td>End of Production History</td><td>The forecast is run from the last date in the historical data. This saves time during the prediction as there is no need to re-run the history after already running a 'Simulation' in the 'History Matching' section.</td></tr>
<tr><td>User Defined</td><td>The user can define any date between the 'Start of Production' and the 'End of the Production' history. This option can be used to compare the Prediction with the Historical data on the last days of the Production History, making sure that the well definitions and well schedule perform properly</td></tr>
</table>
</td></tr>
<tr><td><i>Options</i></td><td>Check the additional options which are to be included in the prediction calculations:
<table>
<tr><td>Use</td><td>If the prediction type 'Reservoir Pressure Only from</td></tr>
</table>
</td></tr>
</table>

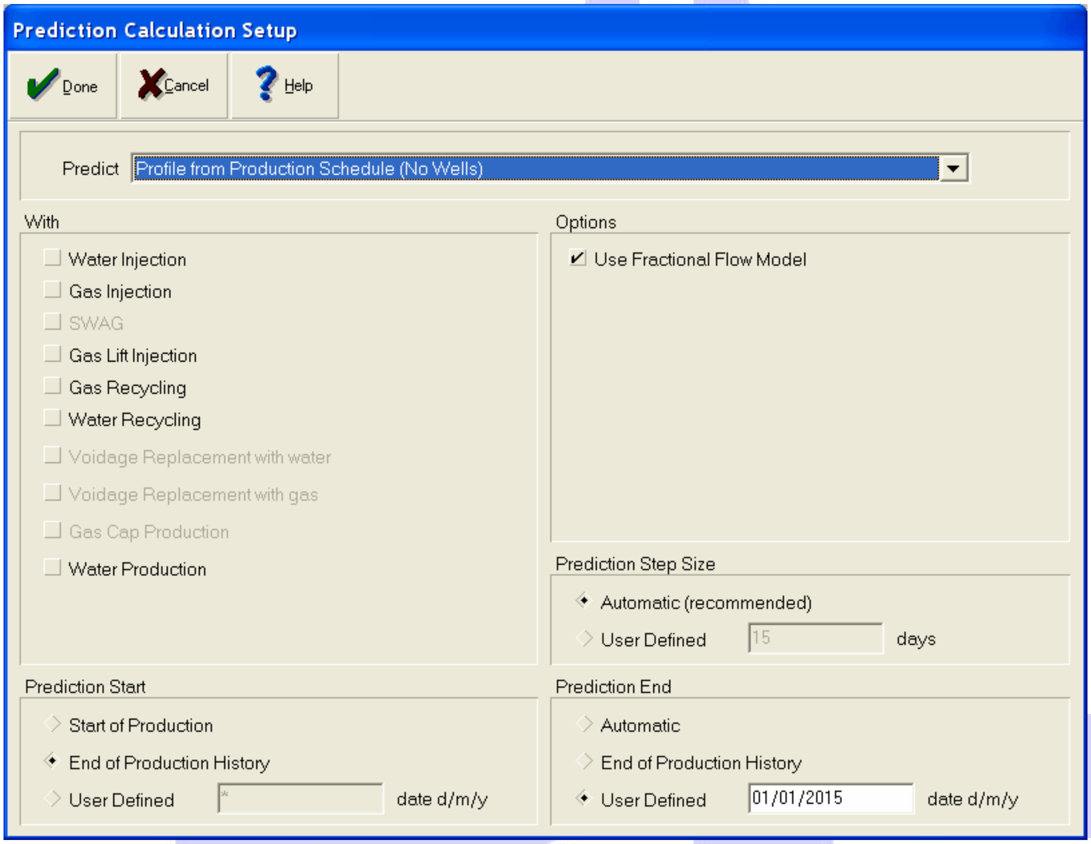
<table>
<tr>
<td></td>
<td>
<table>
<tr>
<td>**Relative Permeabilities**</td>
<td>Production Schedule' is not in use, then it is to the users discretion whether the regressed values are to be used or not.
• If the option is switched on, the principal rate (e.g. oil rate for an oil tank) will be input and **MBAL** will calculate the other rates using the tank relative permeability curves and the breakthrough.
• If the option off is switched off, all three phase rates will be in use. In this case, the tank relative permeabilities and breakthrough will be ignored</td>
</tr>
<tr>
<td>**Calculate Field Potential**</td>
<td>This option is only available for gas and condensate systems.
This option is only available for prediction types 2 and 3 that use prediction wells.
If it is switched on, **MBAL** will calculate the potential of the field at the input manifold pressure if no rate constraints are applied</td>
</tr>
<tr>
<td>**Use DCQ and Swing Factor**</td>
<td>This option is only available for gas and condensate systems. The meaning is different depending on the prediction type.
• For prediction type 'Reservoir Pressure Only from Production Schedule'. If this option is switched on, instead of entering a gas rate for the production schedule, a DCQ production schedule and set of swing factors will need to be input. At each time step, MBal will then use the input DCQ and the swing factor to calculate the required gas rate.
• For prediction type 'Reservoir Pressure and Production from Manifold Pressure Schedule'. If this option is switched on, a min/max DCQ constraint will need to be input. At each time step, **MBAL** will calculate the min/max gas rate by factoring the DCQ min/max by the swing factor</td>
</tr>
</table>
</td>
</tr>
<tr>
<td>**Breakthroughs**</td>
<td>These fields are only shown if the user has selected the "Reservoir Pressure only from Production Schedule" prediction type.
The breakthrough constraints are used to prevent the production of a particular phase until it reaches a particular saturation in the reservoir. This is a control over and above the relative permeabilities that already</td>
</tr>
</table>

<table>
<tr><td></td><td>control the breakthrough saturation by use of residual saturations. The relative permeability curve is shifted linearly so that flow of a particular phase starts at the breakthrough</td></tr>
<tr><td>Prediction Step Size</td><td>The user may specify a reporting step size i.e. how often results for a prediction are reported. This may only be every year, six months or three months. However, for accuracy of calculation the prediction must usually be done with a smaller step size - typically every two weeks. This option allows the maximum step size to be specified for a prediction.
So a prediction step will be done for this minimum step size unless another event (such as a reporting time or change of constraints) occurs first.
<table>
<tr><td>Automatic</td><td>Normally every 15 days - this option should be used unless there is a good reason to do otherwise</td></tr>
<tr><td>User Defined</td><td>Enter the prediction step size in days</td></tr>
</table>
</td></tr>
<tr><td>Prediction End</td><td>This parameter defines when the program will stop the prediction.
<table>
<tr><td>Automatic</td><td>Prediction stops when one of the following conditions is triggered:
• all the wells have stop producing,
• after 80 years of prediction,
• the computer memory is full</td></tr>
<tr><td>End of Production History</td><td>Prediction stops with the last record of the 'Production History'. This option is mainly used to check the quality of the prediction against the 'Production History' before running a full prediction</td></tr>
<tr><td>User Defined</td><td>The user can defined any date after the 'Prediction Start' defined above. This option must be used if no producing periods are considered; for example, in the case of a gas storage</td></tr>
</table>
Chose the relevant options and click Done to register the selections or Cancel to exit the screen</td></tr>
</table>

Examples of Prediction Set up

Prediction of profile with no wells

In this case the production profile needs to be provided by the user (for example the user specifies that the oil production rate will be 5000 bbls/day). The program will then calculate the drop in reservoir pressure for the forecast period, and the corresponding production of water and gas if the fractional flow options (rel perm) have been selected for use. If no rel perms are selected, then the gas and water production rates have to be provided as well (since the mechanism for calculating these is the relative permeabilities).



Predict: Profile from Production Schedule (No Wells)

With
- ☐ Water Injection
- ☐ Gas Injection
- ☐ SWAG
- ☐ Gas Lift Injection
- ☐ Gas Recycling
- ☐ Water Recycling
- ☐ Voidage Replacement with water
- ☐ Voidage Replacement with gas
- ☐ Gas Cap Production
- ☐ Water Production

Options
- ☑ Use Fractional Flow Model

Prediction Step Size
- ● Automatic (recommended)
- ○ User Defined 15 days

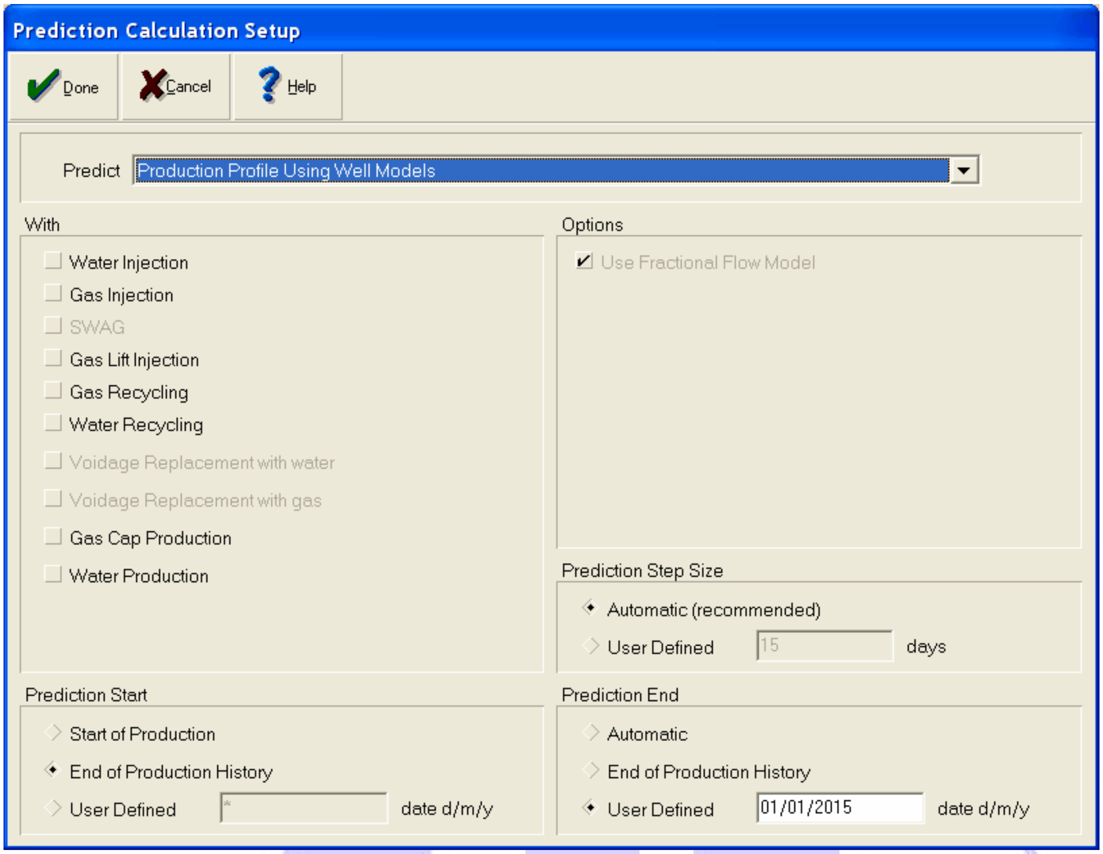
Prediction Start
- ○ Start of Production
- ● End of Production History
- ○ User Defined date d/m/y

Prediction End
- ○ Automatic
- ○ End of Production History
- ● User Defined 01/01/2015 date d/m/y

The user can also select options for pressure support that will be part of the forecast by highlighting the relevant check boxes shown above. The data relevant for these options can then be entered in the “Production and Constraints” screen.

Prediction of profile using well models

Selecting this option will enable the use of well models (VLP/IPR for example) for calculation of rates which will then be used to determine the reservoir pressure drop using the material balance calculations. Once this option is selected, then the fields that enable the user to create well models will become active, as shown below:


Prediction Calculation Setup
Done
Cancel
Help

Predict: Production Profile Using Well Models

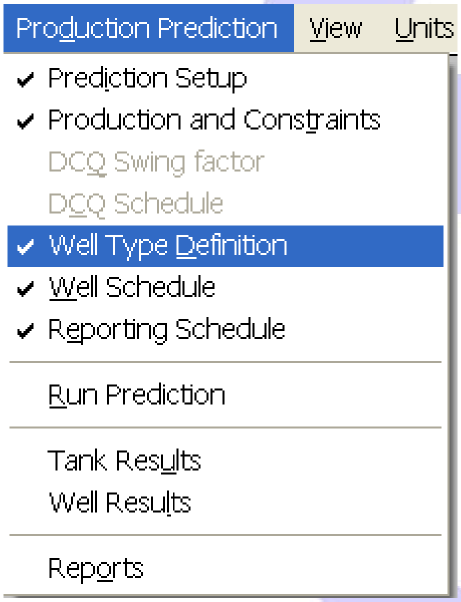
With
☐ Water Injection
☐ Gas Injection
☐ SWAG
☐ Gas Lift Injection
☐ Gas Recycling
☐ Water Recycling
☐ Voidage Replacement with water
☐ Voidage Replacement with gas
☐ Gas Cap Production
☐ Water Production

Options
☑ Use Fractional Flow Model

Prediction Step Size
● Automatic (recommended)
○ User Defined 15 days

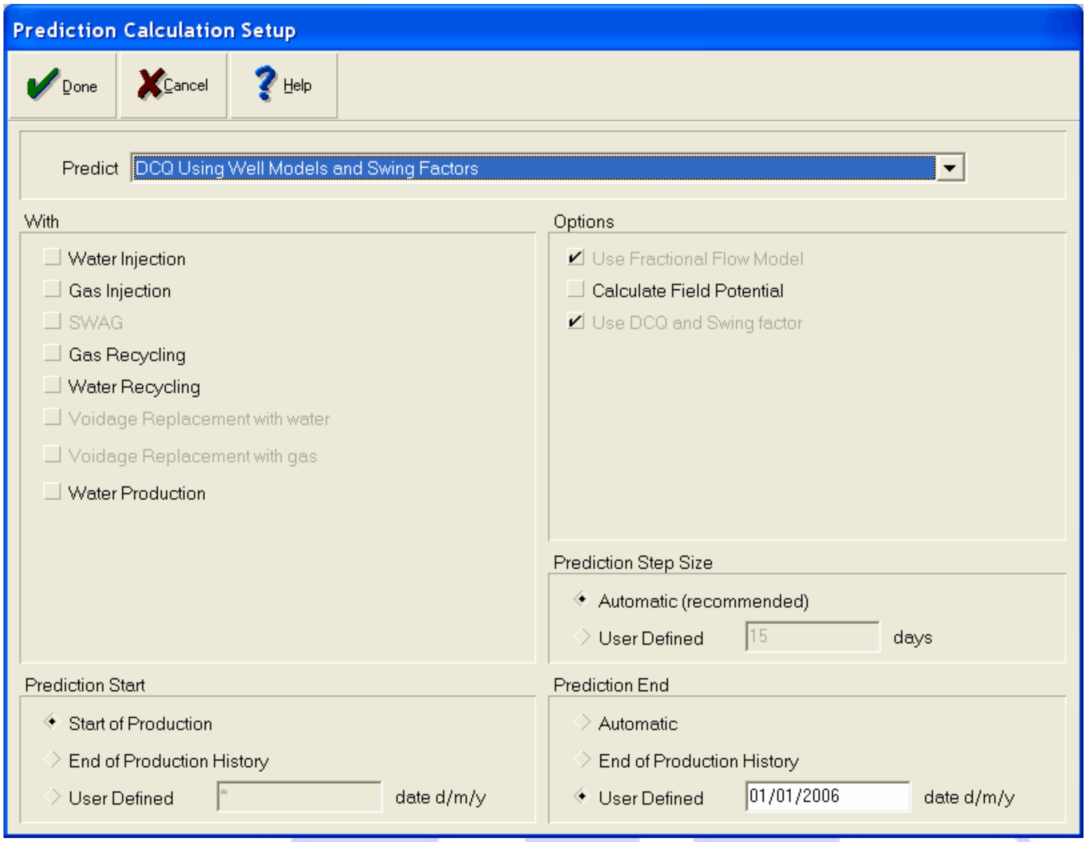
Prediction Start
○ Start of Production
● End of Production History
○ User Defined * date d/m/y

Prediction End
○ Automatic
○ End of Production History
● User Defined 01/01/2015 date d/m/y


Production Prediction
View
Units
✓ Prediction Setup
✓ Production and Constraints
DCQ Swing factor
DCQ Schedule
✓ Well Type Definition
✓ Well Schedule
✓ Reporting Schedule
Run Prediction
Tank Results
Well Results
Reports

Predict DCQ using well models and Swing Factors

This option is available when dealing with a gas system:



Predict: DCQ Using Well Models and Swing Factors

With
☐ Water Injection
☐ Gas Injection
☐ SWAG
☐ Gas Recycling
☐ Water Recycling
☐ Voidage Replacement with water
☐ Voidage Replacement with gas
☐ Water Production

Options
☑ Use Fractional Flow Model
☐ Calculate Field Potential
☑ Use DCQ and Swing factor

Prediction Step Size
● Automatic (recommended)
○ User Defined 15 days

Prediction Start
● Start of Production
○ End of Production History
○ User Defined date d/m/y

Prediction End
○ Automatic
○ End of Production History
● User Defined 01/01/2006 date d/m/y

In this mode the program calculates the maximum daily gas contract quantity that the reservoir can deliver for every year of the prediction period. This can be useful when determining the DCQ quantities to be set in a gas contract. The program in this mode will assume a DCQ and perform a forecast for a year. If the production can be sustained throughout the year, then the DCQ is increased and the forecast for the same time period is carried out again. The iterations stop when the required DCQ can just be achieved.

All of the potentials reported in the predictions refer to potentials calculated without applying constraints, apart from the DCQ prediction.

In the DCQ prediction we need to use the potential to calculate the DCQ. However in this case the potential must be calculated taking into account any constraints existing in the system. In this case the potential will be reported as "potential constrained".

The program accounts for a seasonal swing factor entered in the “DCQ Swing Factor” Table, and a maximum swing factor entered in the “DCQ Schedule” Table. The program also honours (if physically possible) the constraints entered in the “Production and Constraints” table. If well definitions and well schedules are provided, the program calculates the production manifold pressure (or compressor back pressure) required to achieve a DCQ for a yearly period.

Prediction Calculation Technique

At each time step **MBAL** does the following:

- Assumes a tank average pressure
- Calculates the relative permeabilities and fractional flow of the 3 phases
- Calculates the produced GOR/CGR and WC/WGR
- Calculates the individual well production or injection rates and flowing pressures based on:
  - the PVT fluids
  - the IPR
  - the tubing performance curve or constant bottom hole pressure
  - the production/injection constraints
  - the production schedule
- Calculates the water influx for this reservoir pressure and time
- Calculates the tank overall productions and injections
- For multi-tanks, calculates the transmissibility rates
- Calculates the gravity of the gas and water phases
- Calculates the tank's new saturations and assumes a new reservoir pressure
- Iterates until convergence of tank pressure

Calculation and Reporting Time Steps

The *Reporting Frequency* (or time step - see the **Reporting Schedule** dialogue box) can be set by the user to determine the times displayed in the results dialogues. However there are usually extra calculation times between the time steps displayed on the results dialogues or reports.

- The prediction step size defaults to 15 days. This can be changed in the **Prediction Setup** dialogue. Extra calculation times will be inserted based on the prediction step size.
- Changes in production and constraints. An extra calculation time will be inserted whenever there is a change in any of the entries in the **Prediction Production and Constraints** dialogue.
- A calculation time will be inserted if and when the calculation changes from history to prediction mode.
- A calculation time will be inserted whenever a well is started or shut in as defined in the **Well Schedule** dialogue.
- A calculation time will be inserted whenever there is a change in any of the DCQ inputs.

➲ **The various options on performing forecasts are best explained through examples. Please refer to the "Quick Start Guide" examples to see how to perform forecasts with and without wells. The sections below will therefore only provide limited information on the forecast screens.**

2.4.6.3 Production and Constraints

This dialogue box describes the production and injection constraints for the tank. The number and content of the columns will vary depending on the prediction mode and injection options selected in the **Prediction Set-up** dialogue box.

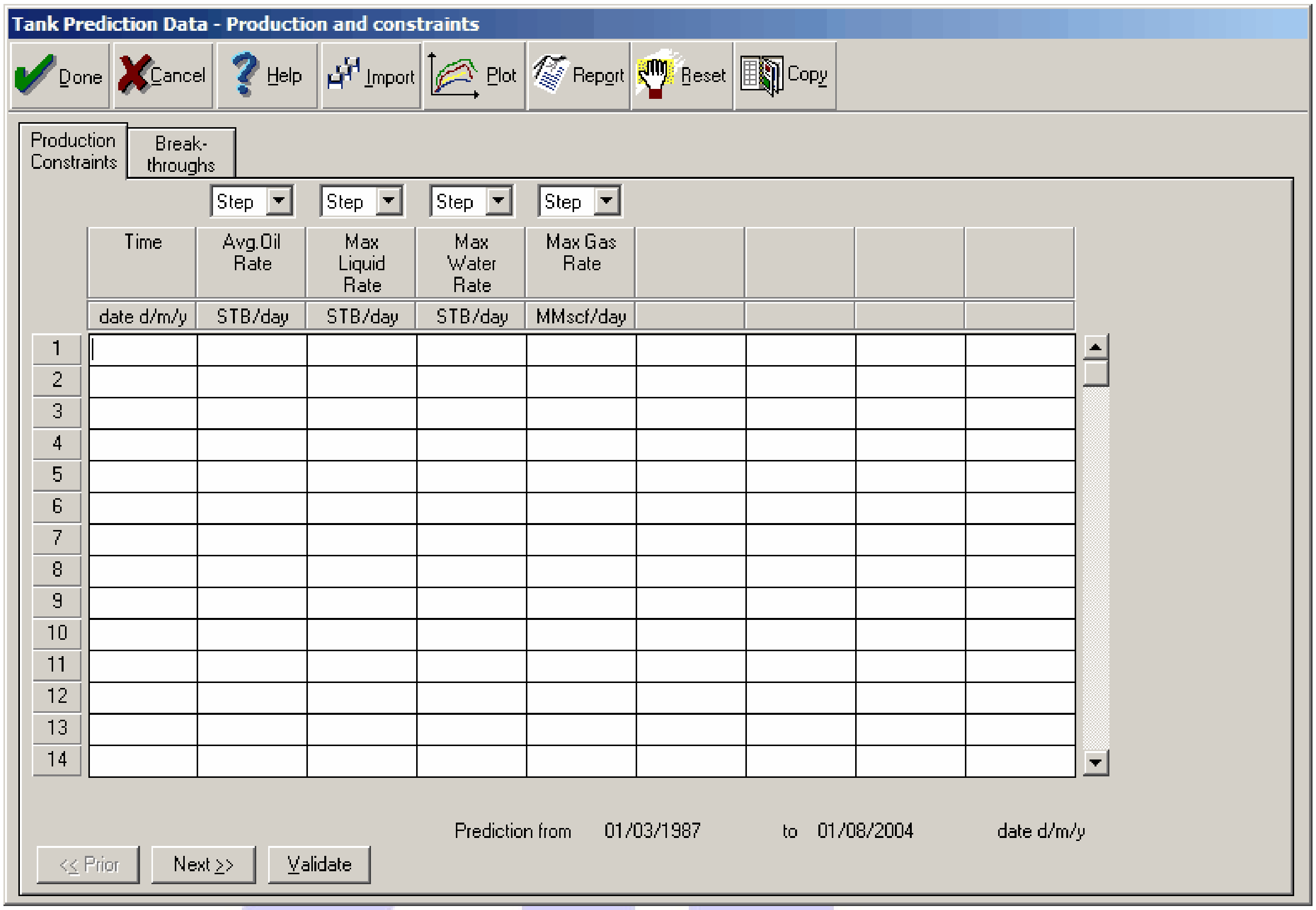
Each column has a combo-box at the top of the column. Use this to switch the interpolation mode for the column. When **Step** is displayed, the parameter will remain constant until redefined.

When **Slope** is, displayed the program performs a linear interpolation between 2 consecutive values of in the column. This table allows entering the different column parameters versus time.

The following rules apply:

Condition	Meaning
A column is left entirely empty	There is no constraint on this parameter.
A column contains only one value.	This parameter will remain constant from that time onwards
The numbered button on the left hand side is depressed	The corresponding line is ignored

The screen for prediction without wells will look like this for a single tank:

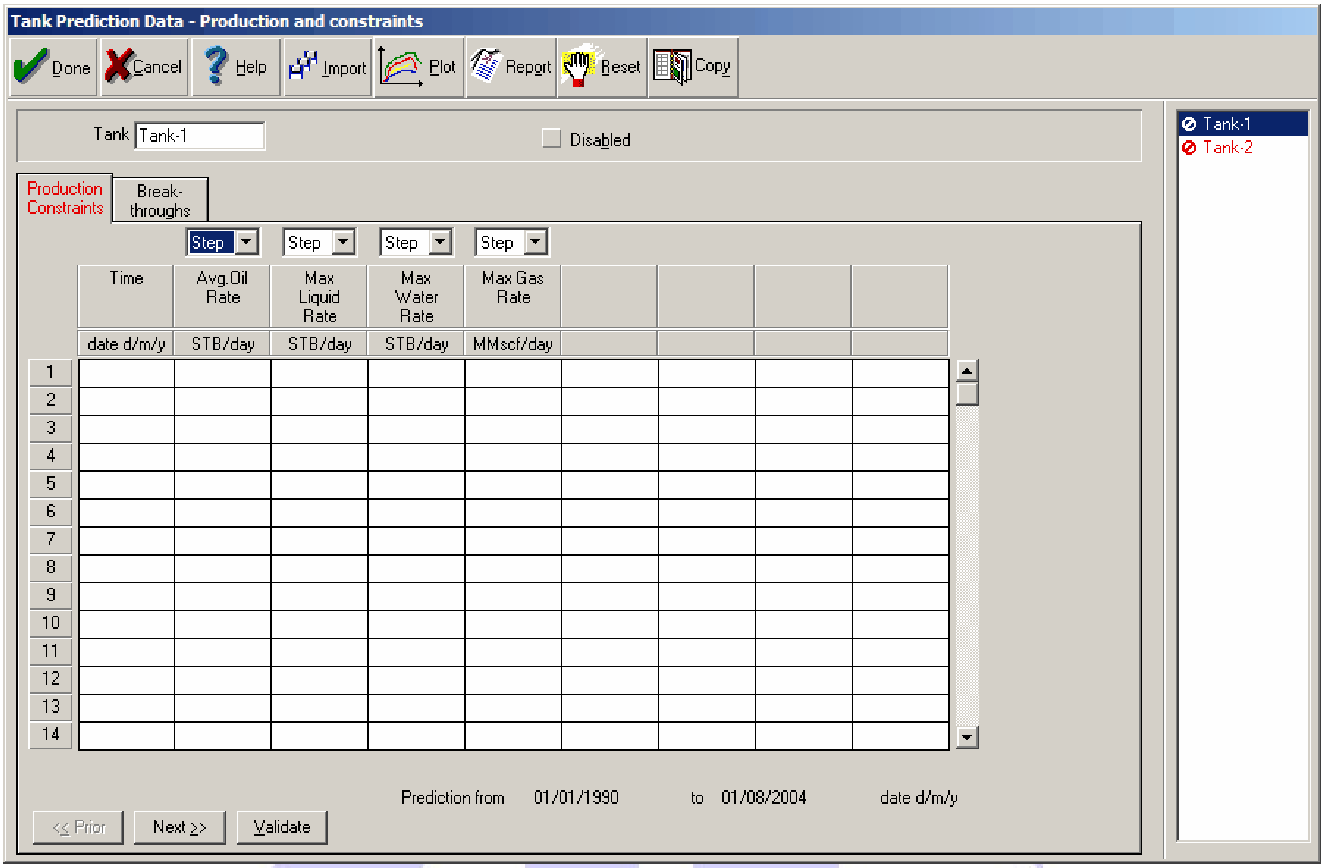

Done
Cancel
Help
Import
Plot
Report
Reset
Copy
Production Constraints
Break-throughs
Step
Step
Step
Step
<< Prior
Next >>
Validate

Tank Prediction Data - Production and constraints

	Time	Avg.Oil Rate	Max Liquid Rate	Max Water Rate	Max Gas Rate				
	date d/m/y	STB/day	STB/day	STB/day	MMscf/day				
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									

Prediction from 01/03/1987 to 01/08/2004 date d/m/y

Whereas the screen for a multitank system for example will look like this:


Tank Prediction Data - Production and constraints
Done
Cancel
Help
Import
Plot
Report
Reset
Copy
Disabled
Production Constraints
Break-throughs
Step
Step
Step
Step
Time
Avg.Oil Rate
Max Liquid Rate
Max Water Rate
Max Gas Rate
date d/m/y
STB/day
STB/day
STB/day
MMscf/day
1
2
3
4
5
6
7
8
9
10
11
12
13
14
<< Prior
Next >>
Validate
Tank-1
Tank-2

Tank Tank-1

Prediction from 01/01/1990 to 01/08/2004 date d/m/y

Different constraints can be put on each tank which the program will take into account during the forecast.

Input Fields

Man Pres	Defines the production manifold pressure for predictions with wells
Oil/Gas/Water Rate	Defines the production rates if using prediction type 'Reservoir Pressure only from Production Schedule'. If the relative permeabilities are to be used during the prediction run, only the fluid rate for the principal fluid (e.g. oil rate for oil tank) is required
Maximum Oil/Gas/Liquid Rate	Defines the maximum production rate constraint. When one of these constraints is triggered, the program raises the production manifold pressure in order to satisfy the constraint
Minimum Oil/Gas/Liquid Rate	Defines the minimum production rate constraint. When one of these constraints is triggered, the program shuts down all of the production wells (apart from gas cap and aquifer producers). This means it is effectively an abandonment constraint
Voidage Replacement	Defines the fraction of the reservoir pore volume to be replaced with the injection fluid and could be larger than 100% if repressurisation of the reservoir is modelled. When injection wells have been defined in the Well Definitions screen and are included in the Drilling Schedule the prediction will calculate the rates required from these wells to achieve the Voidage

	Replacement target. The option can be started or altered at any time during the production of the reservoir and to stop the replacement a value of 0% needs to be input. Voidage Replacement is independent of the Water/Gas Recycling and Water/Gas Recycling Cut-off constraints. Please see Voidage Replacement and Injection for details of using these two options together
Gas Injection Manifold Pressure	Defines the gas injection manifold pressure. This parameter may be overridden by the minimum / maximum gas injection rate parameter
Gas Injection Rate	Defines the production rate of the main phase. This parameter may be overridden by the minimum / maximum Manifold Pressure
Minimum/ Maximum Gas Injection Manifold Pressure	Defines the pressure constraints on the gas injection manifold. When one of these constraints is triggered, the program changes the gas injection rate in order to satisfy the constraint
Maximum Gas Injection Rate	Defines the maximum gas injection rate constraint. When one of these constraints is triggered, the program reduces the gas injection manifold pressure in order to satisfy the constraint
Minimum Gas Injection Rate	Defines the gas injection rate constraints. When one of these constraints is triggered, the program shuts down all of the gas injection wells
Injection Gas Gravity	This value is used to calculate the average gas gravity of the gas cap (if any) and affects the gas cap PVT properties. Leave blank if the injected gas gravity is the same as the gravity of the gas produced. The original gravity of the gas in place will already have been defined in the PVT
Gas Recycling	The Recycling input field signals the program to automatically re-inject this fraction amount of the gas production. The gas is re-injected without using Tubing Performance Curve and these injection wells do not need to be included in the Well Schedule. On the other hand, this re-injection is taken into account in the calculation of the maximum gas injection rate above
Gas Recycling Cut-off	Defines the cut-off GOR for the Gas Recycling. The program stopped the gas recycling if the producing GOR exceeds this value
CO2, H2S, N2 Mole %	Defines the mole percent of impurity in the gas injected. These percentages are used to calculate the reservoir average gas content in H2S, CO2, and N2. The original constraints of the gas in place are defined in the PVT section. If these fields are left blank, the program assumes that the content in CO2, H2S, and N2 is the same as the gas produced
Water Injection Manifold Pressure	Defines the water injection manifold pressure. This parameter may be overridden by the minimum / maximum water injection rate parameter
Minimum/ Maximum Water Injection Manifold	Defines the pressure constraints on the water injection manifold. When one of these constraints is triggered, the program changes the water injection rate in order to satisfy the constraint

Pressure	
Maximum Water Injection Rate	Defines the maximum water injection rate constraint. When one of these constraints is triggered, the program reduces the water injection manifold pressure in order to satisfy the constraint
Minimum Water Injection Rate	Defines the minimum water injection rate constraints. When one of these constraints is triggered, the program shuts down all of the water injection wells
Water Injection - Water Salinity	This value is used to calculate the average water salinity of the water in the pore volume and affects the water compressibility calculation. Leave blank if the salinity of the injected water is the same than the salinity of the water produced. The original water salinity is defined in the PVT
Water Recycling	The 'Recycling' input field signals the program to automatically re-inject this fraction amount of the water production. The water is re-injected without using 'Tubing Performance Curve' and these injection wells do not need to be included in the 'Well Schedule'. On the other hand, this re-injection is taken into account in the calculation of the maximum water injection rate above
Water Recycling Cut-off	Defines the cut-off WC for the Water Recycling so water recycling will be stopped if the producing WC exceeds this value
Maximum Gas Cap Manifold Rate	Defines the maximum gas cap manifold rate constraint. When one of these constraints is triggered, the program reduces the gas cap manifold pressure in order to satisfy the constraint. There are special rules applied to the maximum gas cap rate constraint if a maximum gas rate has also been entered. The maximum gas rate constraint is treated as the maximum gas rate from the oil wells plus the gas from the gas cap producers. The process is as follows: • Calculate the oil wells and modify the oil well manifold pressure to obey the gas rate constraint if necessary. • Calculate the difference between the gas rate from the oil wells and the maximum gas rate constraint. If this is less than the gas cap maximum rate then reset the gas cap maximum rate to the difference. This means that if the oil wells reach the maximum gas rate, gas cap production will be stopped.
Minimum Gas Cap Manifold Rate	Defines the minimum gas cap manifold rate constraint. When one of these constraints is triggered, the program shuts down all of the gas cap producer wells
DCQ Max	*(For Reservoir Pressure and Production from manifold Pressure Schedule prediction type)* Defines the maximum gas DCQ. At each time step, **MBAL** will calculate the maximum gas constraint from the maximum DCQ and the swing factors. It will then raise the manifold pressure in order to satisfy the calculated maximum gas constraint. The program checks this constraint against the average rate

DCQ Min	*(For Reservoir Pressure and Production from manifold Pressure Schedule prediction type)* Defines the minimum gas DCQ. At each time step, **MBAL** will calculate the minimum gas constraint from the maximum DCQ and the swing factors. When one of these constraints is triggered, the program shuts down all the production wells (apart from the aquifer producers). This means it is effectively an abandonment constraint
DCQ Max	*(For DCQ from Manifold Pressure Schedule and Swing Factor prediction type)* Defines the maximum gas DCQ that **MBAL** should calculate. **MBAL** will raise the manifold pressure in order to satisfy this constraint

NOTE:
For the 'General' material balance option, there are options to have different manifold pressures for the oil wells and the gas wells. In this case a pressure must be entered for the oil leg manifold and the gas cap manifold. Different min/max rate constraints can be entered for the oil leg manifold and the gas cap manifold productions.

A 'Copy' button is available in single tank mode which can be used to copy the current calculated history simulation results into the corresponding constraint columns. This can then be used to verify the relative permeability curves by checking if the simulation results can be reproduced in prediction mode.

Command Buttons

Plot	Displays a graph of the constraints to check the quality and validity of the data
Report	Allows output of a listing of the constraints
Reset	This options can be used to delete all the data from the table
Import	This option can be used to import data from an external database or text file
Layout	This option can be used to select which columns to display in the table
Copy	This option is only available in single tank mode. It can be used to copy the current calculated history simulation results into the corresponding constraint columns. These can then be used to verify the relative permeability curves by checking if the simulation results can be reproduced in prediction mode

2.4.6.3.1 Voidage Replacement and Injection

When voidage replacement and injection options are selected in the 'Prediction Setup', some special rules apply. These rules are true whether the voidage replacement and injection are applied to gas or water.

The first situation is when both options are selected but there are no injection wells of the corresponding fluid.

In this case, **MBAL** will calculate the amount of injection fluid required to replace all the fluid produced for each time step. It then factors this injection rate by the voidage replacement percentage entered in the 'Production and Constraints' dialogue. This rate of fluid will then be injected into the tank for the given time step. No wells are needed to do this so **MBAL** always injects the full amount. Note that the voidage is recalculated at each time step.

The second situation is when both options are selected but injection wells of the corresponding fluid are currently in operation as specified in the well schedule.

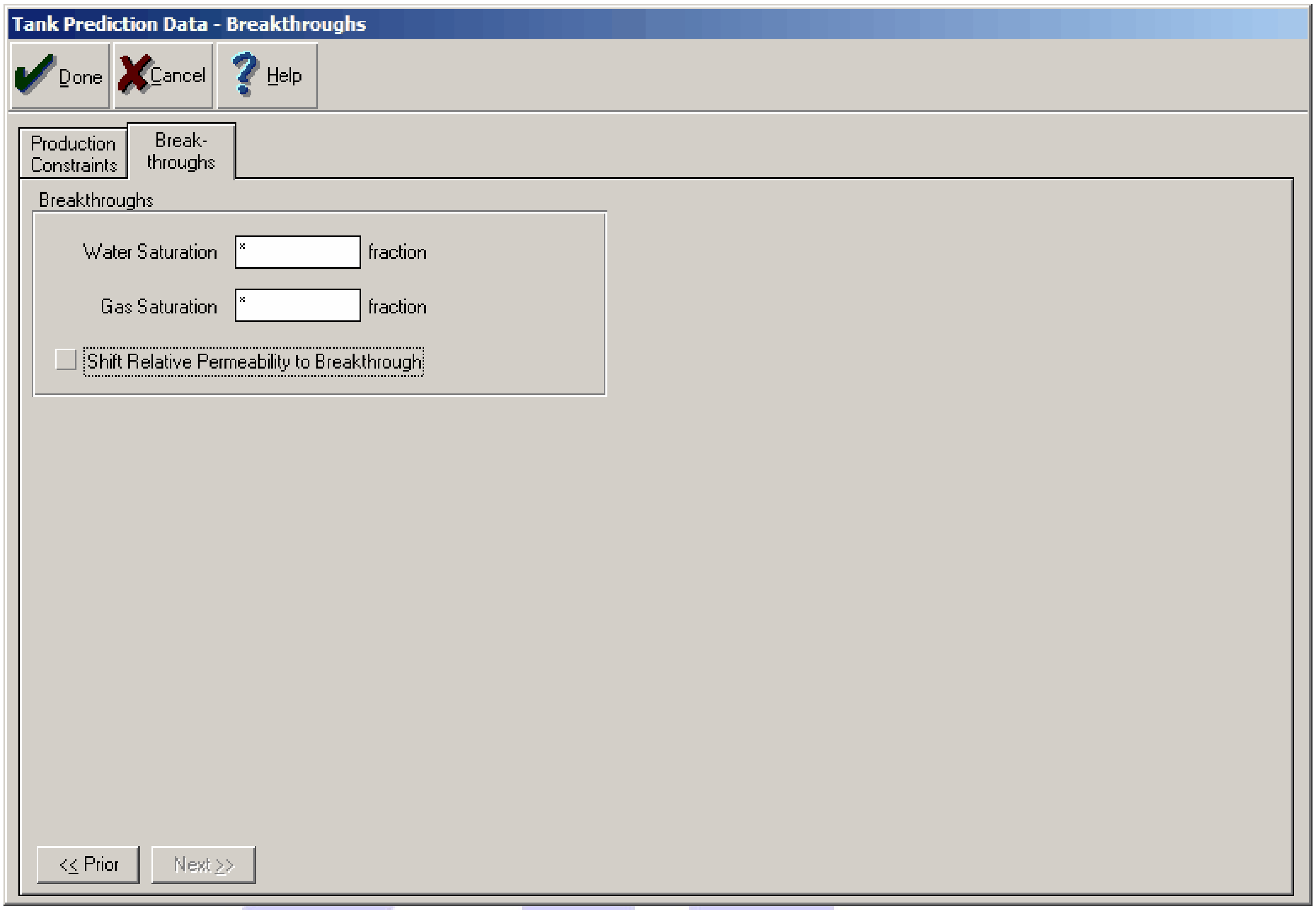
In this case **MBAL** again calculates the amount of injection needed including the voidage replacement percentage (as described above). However, rather than simply injecting this amount, **MBAL** will set the value as a maximum injection constraint. This means that the full amount will only be injected if the injection wells can achieve this injection rate - otherwise it will only inject what it can. If a maximum injection constraint has also been entered then it will honour the lesser of the two values.

Since we only have one maximum injection constraint for the whole system which can only be controlled by a single injection manifold pressure, this second method can only be guaranteed to work if only one tank and one injection well are defined in the model.

It should also be noted that both of these situations can occur in a single prediction run, as **MBAL** will check at each time step if any injection wells are in operation and if a voidage replacement percentage greater than zero has been entered.

2.4.6.4 Breakthrough Saturations

This screen allows the entry of Breakthrough saturations for the prediction.


Tank Prediction Data - Breakthroughs
Done
Cancel
Help
Production Constraints
Break-throughs
Breakthroughs

Water Saturation * fraction

Gas Saturation * fraction

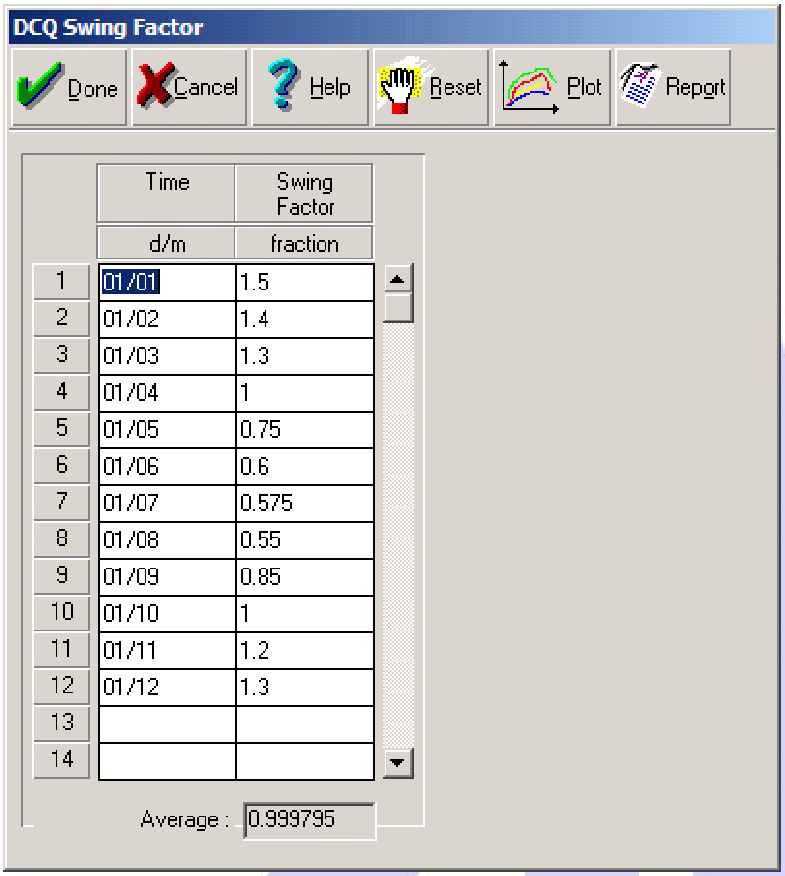
☐ Shift Relative Permeability to Breakthrough

<< Prior
Next >>

Water and gas breakthrough saturations can be entered, along with a choice of shifting the relative permeability to the breakthroughs (change the residual saturations in the rel perm tables) or not.

2.4.6.5 DCQ Swing Factor (Gas reservoirs only)

This dialogue box describes the daily gas contract (DCQ) swing factor over a period of one calendar year. The instantaneous gas production rate is the product of the DCQ and Swing Factor.



	Time	Swing Factor
	d/m	fraction
1	01/01	1.5
2	01/02	1.4
3	01/03	1.3
4	01/04	1
5	01/05	0.75
6	01/06	0.6
7	01/07	0.575
8	01/08	0.55
9	01/09	0.85
10	01/10	1
11	01/11	1.2
12	01/12	1.3
13		
14		

Average : 0.999795

Input Fields

Time	Enter the day and month at which the new swing factor should be applied
Swing factor	Enter the correction to be applied to the DCQ to obtain the production gas rate from that point in time until the next record

At the bottom of the swing factor column there is an ***Average*** field. This is average value of the swing factor over the year recalculated by **MBAL** whenever any of the swing factors are changed.

Note that the program automatically loops back to the top of the table when the last record is reached (i.e. only one calendar year needs to be described).

See Table Data Entry for more information on entering the DCQ swing factors.

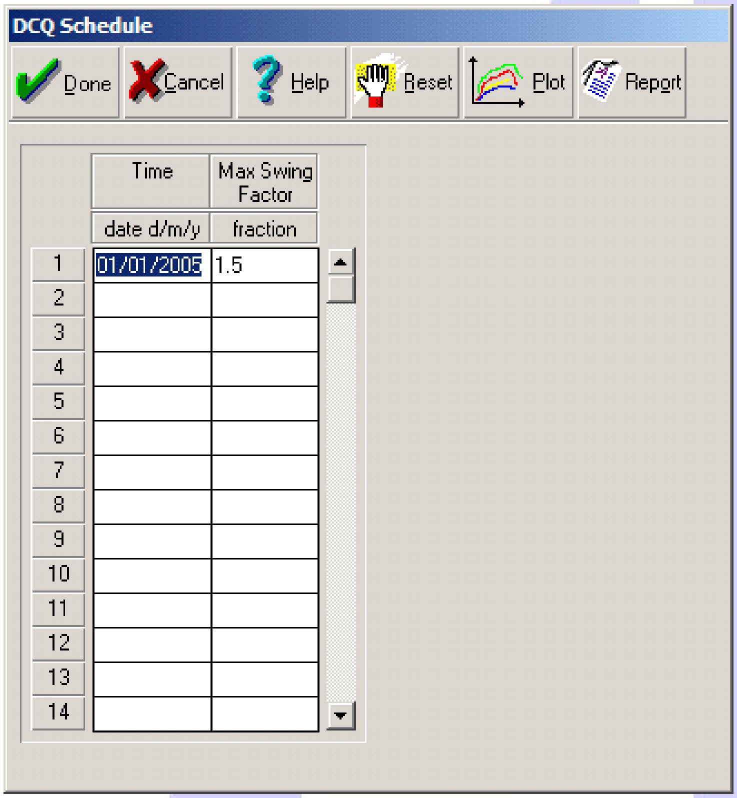
Command Buttons

Plot	Displays a graph of the swing factors to check the quality and validity of the data

Report	Allows output of a listing of the swing factors
Reset	This options can be used to delete all the data from the table

2.4.6.6 DCQ Schedule

This dialogue box defines the time at which the program should begin calculating a new DCQ. The DCQ is maintained constant between two consecutive entries:



	Time	Max Swing Factor
	date d/m/y	fraction
1	01/01/2005	1.5
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		

Input Fields

Time	Defines the next allowed change for a new DCQ. The start time of prediction must be the top entry
Max. Swing Factor	Depending on the gas contract, the gas producer may be required to produce above the DCQ for a short period of time. The maximum swing factor can be used to insure that the reservoir will be able to produce DCQ * Max Swing at any time. In other words, the program makes sure that the potential of the reservoir is at least DCQ * Max Swing. These values only need to be entered when the max swing factor changes. The program maintains the Max. Swing Factor constant until a new factor is encountered in the list

The timing of the peaks in the Swing Factor and the DCQ schedule breaks may affect the calculated DCQ. If the maximum swing is required to be produced near the end of the DCQ contract period, then additional deliverability would be needed if the peak swing occurred nearer the beginning of the contract period.

The timing of the peaks in the Swing Factor and the DCQ schedule breaks may affect the calculated DCQ. If the maximum swing is required to be produced near the end of the DCQ contract period, then additional deliverability would be needed if the peak swing occurred nearer the beginning of the contract period.

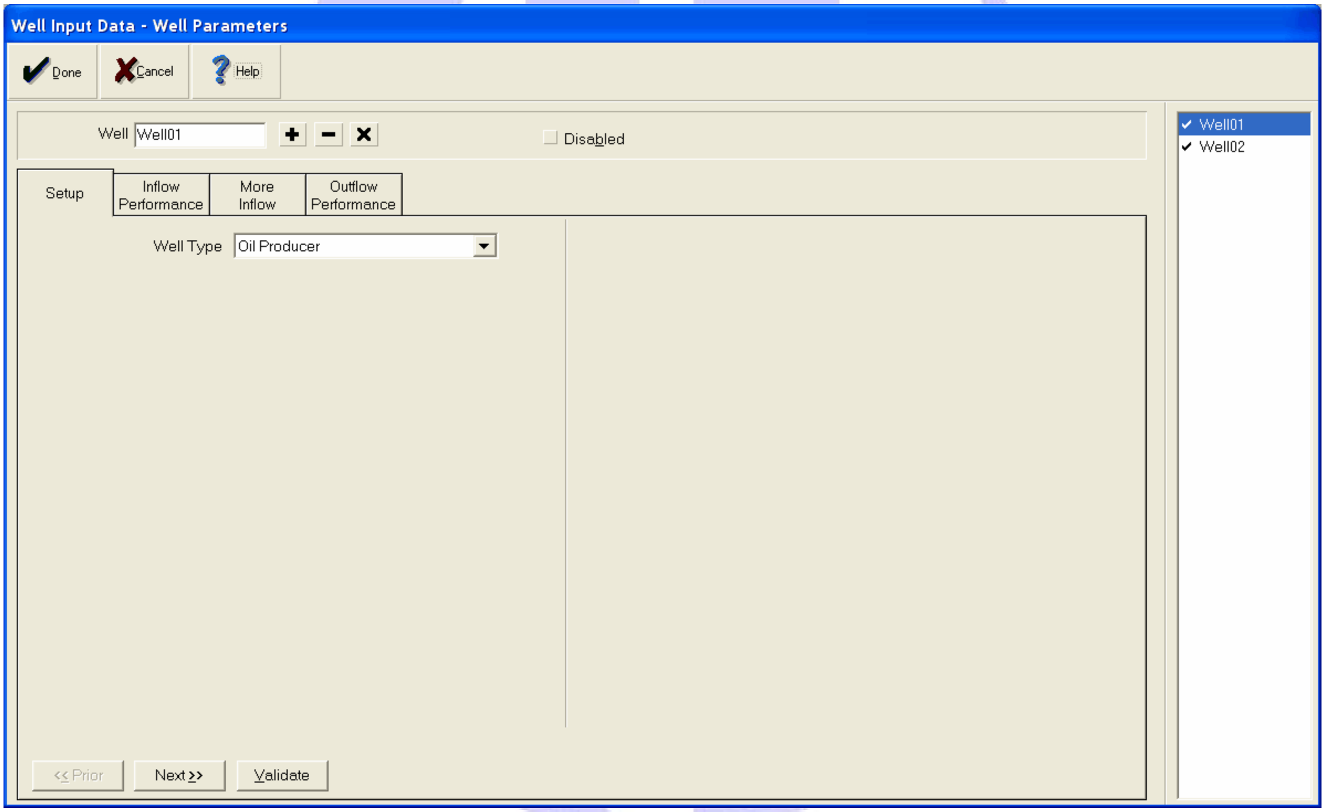
Command Buttons

Plot	Displays a graph of the DCQ schedule to check the quality and validity of the data
Report	Allows output of a listing of the DCQ schedule
Reset	This options can be used to delete all the data from the table

See Table Data Entry for more information on entering the DCQ schedule.

2.4.6.7 Well Type Definitions

This dialogue is used to define the properties and constraints of a well or group of wells.



Well Input Data - Well Parameters

Well: Well01

☐ Disabled

Well Type: Oil Producer

✔ Well01
✔ Well02

Once the well type definitions are established, these definitions are used through the well schedule to drive the production prediction calculations.

The dialogue is split into three data pages:

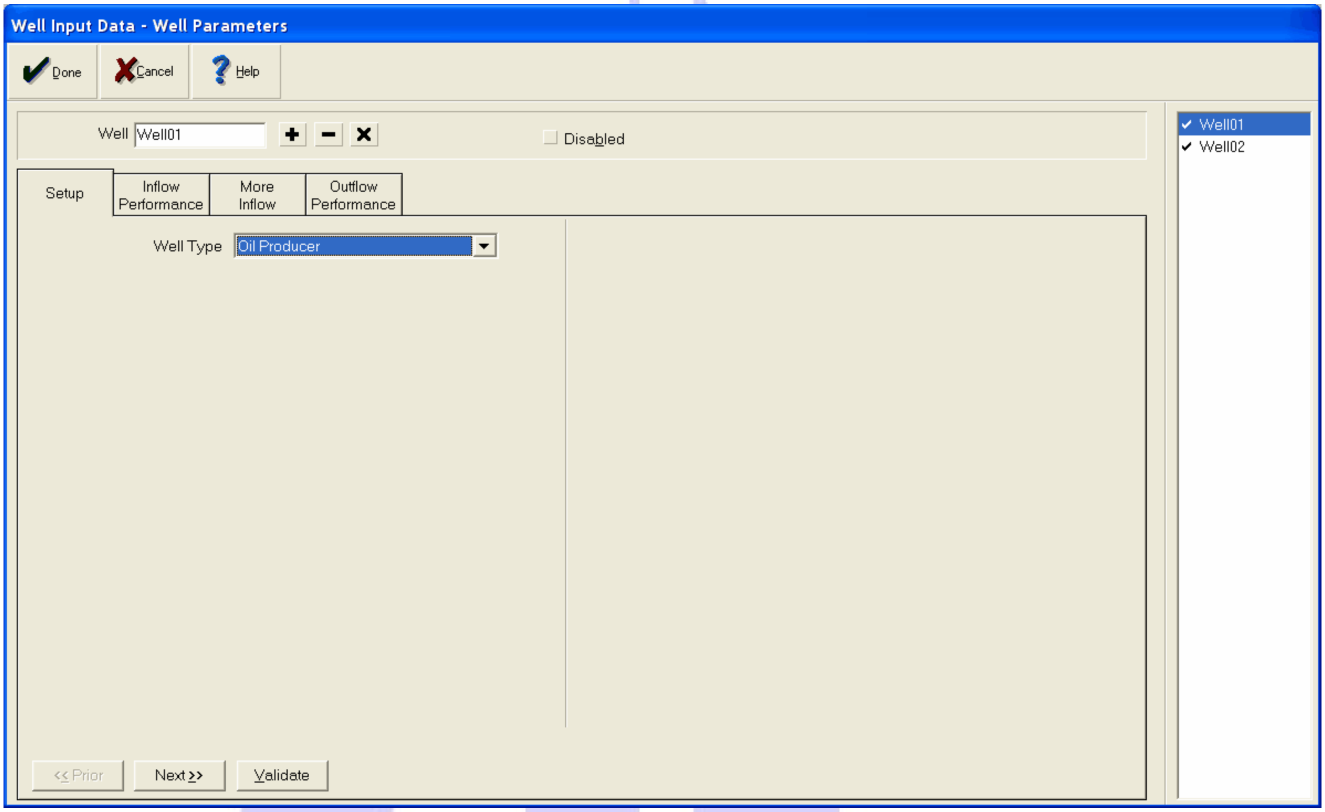
Setup	The well type can be defined in this screen
Inflow Performance	The parameters for the IPR (including Gravel Pack) and layer constraints can be entered
More Inflow	Information on abandonment and breakthrough constraints can be entered here
Outflow Performance	The parameters for the tubing performance and the well constraints are defined in this page

Command buttons

Creating a new well definition	If new wells are to be defined click the ⊞ command button in the well data dialogue box or press the **Add** icon button. Enter the desired well identifier in the **Name** field, select the well type and supply the rest of the data for the well. If a copy of an existing well definition is needed, firstly, select the required well and then The click on the ☒ button. Enter the desired well identifier in the **Name** field
Selecting a well definition	To select another well definition, select a well from the list display to the right of the well data window. To pick a well definition, click to highlight the well name, or use the or arrows to choose a well
Deleting a well definition	To delete a well from the list, first call up the desired well and display its definition on the screen. Click the ⊟ command button. **MBAL** will ask for confirmation of the deletion

2.4.6.7.1 Well Type Setup

The **Well** dialogue **Setup** tab is used to setup *a well or group of wells* .


Well Input Data - Well Parameters
Done
Cancel
Help
Well
+
−
×
Setup
Inflow Performance
More Inflow
Outflow Performance
<< Prior
Next >>
Validate
Well01
Well02

Well: Well01

☐ Disabled

Well Type: Oil Producer

Input Fields

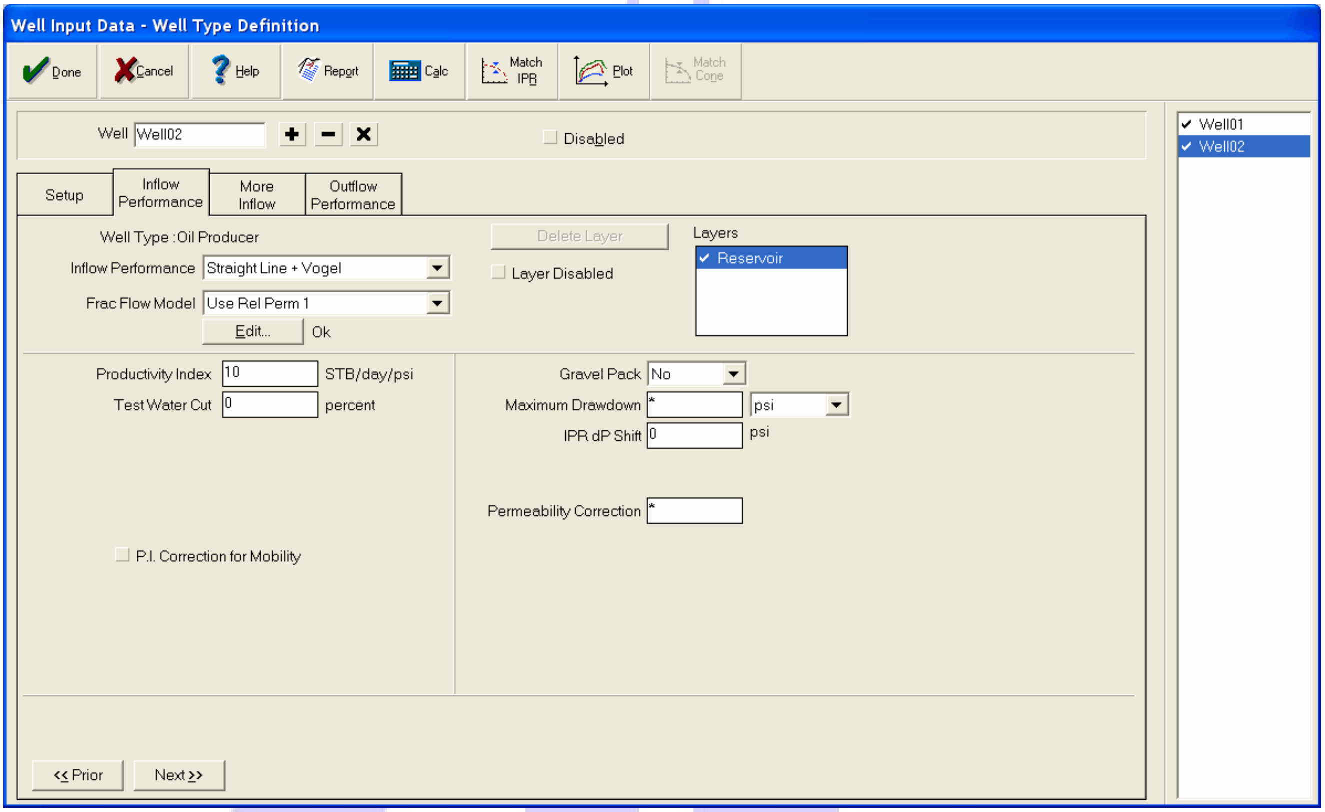
Well Type	Defines the flow type of the well
Tanks	(multi-tank only) Defines which tanks the well is connected to (for multi-tank only). Highlighted tanks in the list indicate that these are connected to the well

Set-up

- Select a well from the list to the right of the screen screen.
- Next, select the well type from a drop down list containing a variable selection of flow types. The well type selected determines the remaining data sheets to be entered. Data sheets containing invalid information for the well type selected will automatically be highlighted in RED.
- Press 'Validate' to run the validation procedure and pinpoint the input error. If no further data is required for the well, the data sheet(s) may be accessed.

2.4.6.7.2 Well Inflow Performance

This tab is used to enter the IPR data, relative permeabilities and the layer constraints:


Well Input Data - Well Type Definition
Done
Cancel
Help
Report
Calc
Match IPR
Plot
Match Cone
Disabled
Setup
Inflow Performance
More Inflow
Outflow Performance
Delete Layer
Layer Disabled
Edit...
P.I. Correction for Mobility
<< Prior
Next >>
✓ Well01
✓ Well02

Well Well02

Well Type : Oil Producer

Inflow Performance Straight Line + Vogel

Frac Flow Model Use Rel Perm 1

Ok

Layers ✓ Reservoir

Productivity Index 10 STB/day/psi

Test Water Cut 0 percent

Gravel Pack No

Maximum Drawdown * psi

IPR dP Shift 0 psi

Permeability Correction *

Input Fields

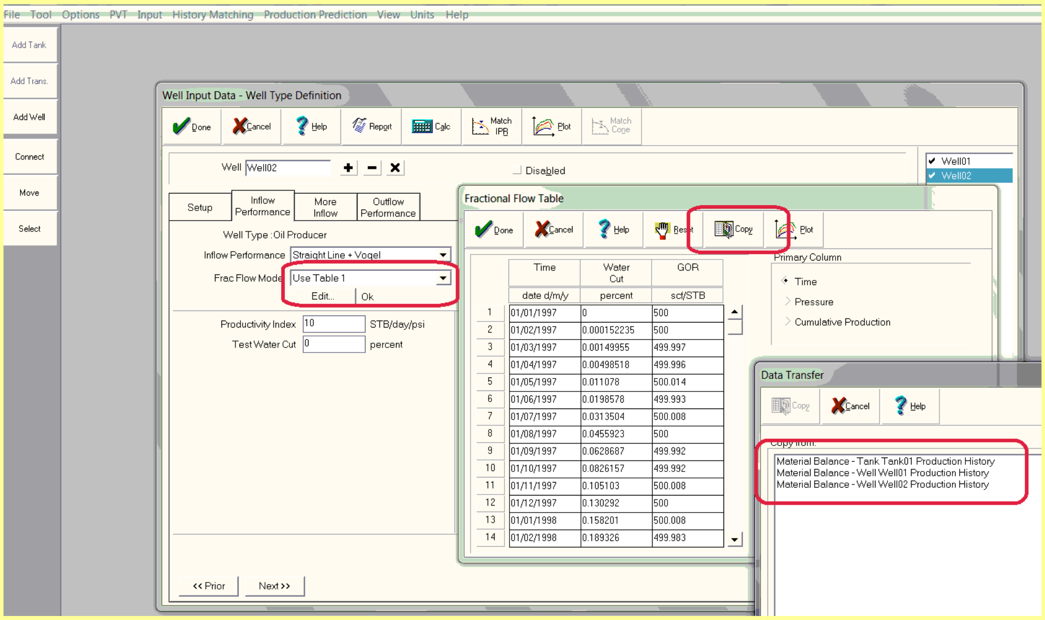
Layers	For multi-layer wells, this list box is used to select which IPR is in use in this data sheet
Layer Disabled	Set this button to 'on' if a layer is to be temporarily disabled (i.e. the tank connected to the current well) for the purposes of the calculation. This allows a layer to be removed from the calculation without deleting it permanently
Gas Coning	This button is only visible if the gas coning option has been set in the tank connected to the selected layer. Set this button to 'on' if gas coning for this layer is to be modelled. If gas coning is used, the production prediction will calculate the GOR for a layer using a gas coning model rather than using the relative permeability. Water cut will still be calculated from the relative permeability curves. The gas coning model can be matched for each layer by clicking on the **Match Cone** button. The gas coning model is based on "Urbanczyk, C.H. and Wattenbarger, R. A.: "Optimization of Well Rates under Gas Coning Conditions," SPE Advanced Technology Series, Vol. 2, No. 2". The original method has been

	significantly altered to allow rate prediction
Water Coning	This button is only visible if the water coning option has been set in the tank connected to the selected layer. Set this button to 'on' if water coning is to be modelled for this layer. If water coning is used, the production prediction will calculate the WC for a layer using a gas coning model rather than using the relative permeability. GOR will be calculated from the relative permeability curves. The water coning model can be matched for each layer by clicking on the **Match Cone** button which displays the 'Water Coning Matching' dialogue. The water coning model is based on "Bournazel-Jeanson, Society of Petroleum Engineers of AIME, 1971". The time to breakthrough is proportional to the rate. For low rates the breakthrough may never occur. After breakthrough the WC develops roughly proportionally to the log of the Np, to a maximum water cut
Inflow Performance	Defines the well **IPR** type. The data to be entered for the IPR type selected will be displayed in the panel below the selection box (e.g. Productivity Index). For more information on the different models and the associated data see Inflow Performance (IPR) Models below
Permeability Correction	This factor can be used to correct the inflow performance for changing permeability in the tank as the pressure decreases. $k = k_i \left(1.0 + C_f \left(P - P_i\right)\right)^N$ The permeability decrease is proportional to the ratio of the current pore volume to the initial pore volume raised to a power. To apply the model, we calculate the correction term to the initial permeability for the current reservoir pressure then: • For Straight line and Vogel model we multiply the productivity index by the permeability correction. • For Forchheimer and Forchheimer Pseudo model we divide the Darcy term by the permeability correction. • For C&N model we multiply the C term by the permeability correction
Gravel pack	Select this option to model a gravel pack. For more information see Gravel Pack 301
Frac Flow Rel Perms	Used to select which set of relative permeabilities should be used for fractional flow calculations for this layer. If *Use Tank* is selected then the relative permeabilities are taken from the tank for the layer. There are also two other sets of relative permeabilities stored in the layer. It may be desired to use one of these sets for fractional flow calculations instead of the tank relative permeabilities. If *Use Rel Perm 1 or Use Rel Perm 2* is selected then the user may click the **Edit** button to view/edit the selected set

<table>
<tr><td></td><td>of relative permeabilities

<i>NEW in IPM8.0</i>

Selecting <i>Table 1</i> for fractional flow then pressing <i>Edit|Copy</i> allows the production history to be directly imported and used for predictions rather than using a Corey function based upon regression from history matching.



File Tool Options PVT Input History Matching Production Prediction View Units Help
Add Tank
Add Trans.
Add Well
Connect
Move
Select
Well Input Data - Well Type Definition
Done
Cancel
Help
Report
Calc
Match IPR
Plot
Match Cone
Setup
Inflow Performance
More Inflow
Outflow Performance
Disabled
Well01
Well02
<< Prior
Next >>
Fractional Flow Table
Done
Cancel
Help
Reset
Copy
Plot
Primary Column
Time
Pressure
Cumulative Production
Data Transfer
Copy
Cancel
Help

Well: Well02
Well Type : Oil Producer
Inflow Performance: Straight Line + Vogel
Frac Flow Mode: Use Table 1
Edit... Ok
Productivity Index: 10 STB/day/psi
Test Water Cut: 0 percent

<table>
<tr><th></th><th>Time</th><th>Water Cut</th><th>GOR</th></tr>
<tr><th></th><th>date d/m/y</th><th>percent</th><th>scf/STB</th></tr>
<tr><td>1</td><td>01/01/1997</td><td>0</td><td>500</td></tr>
<tr><td>2</td><td>01/02/1997</td><td>0.000152235</td><td>500</td></tr>
<tr><td>3</td><td>01/03/1997</td><td>0.00149955</td><td>499.997</td></tr>
<tr><td>4</td><td>01/04/1997</td><td>0.00498518</td><td>499.996</td></tr>
<tr><td>5</td><td>01/05/1997</td><td>0.011078</td><td>500.014</td></tr>
<tr><td>6</td><td>01/06/1997</td><td>0.0198578</td><td>499.993</td></tr>
<tr><td>7</td><td>01/07/1997</td><td>0.0313504</td><td>500.008</td></tr>
<tr><td>8</td><td>01/08/1997</td><td>0.0455923</td><td>500</td></tr>
<tr><td>9</td><td>01/09/1997</td><td>0.0628687</td><td>499.992</td></tr>
<tr><td>10</td><td>01/10/1997</td><td>0.0826157</td><td>499.992</td></tr>
<tr><td>11</td><td>01/11/1997</td><td>0.105103</td><td>500.008</td></tr>
<tr><td>12</td><td>01/12/1997</td><td>0.130292</td><td>500</td></tr>
<tr><td>13</td><td>01/01/1998</td><td>0.158201</td><td>500.008</td></tr>
<tr><td>14</td><td>01/02/1998</td><td>0.189326</td><td>499.983</td></tr>
</table>

Copy from:
Material Balance - Tank Tank01 Production History
Material Balance - Well Well01 Production History
Material Balance - Well Well02 Production History</td></tr>
<tr><td>Maximum Drawdown</td><td>Enter a value in this field if the maximum delta P of the formation is to be enforced. If the delta P of the formation rises above this value, the program will calculate the dP choke necessary to give the delta P of the formation equal to the entered maximum value (and thus reduce the layer rate). Leave blank if a maximum drawdown is not to be applied</td></tr>
<tr><td>IPR dP

Shift</td><td>This field is used to shift the IPR pressure. The program will add the shift to the reservoir pressure before calculating the IPR.

For variable PVT, a Calculate button is shown next to this field. If this button is selected it will calculate the shift required to shift the tank pressure datum to the BHP datum depth which is entered in the 'Outflow Performance' tab</td></tr>
<tr><td>Top Perf (TVD)
Bottom Perf (TVD)</td><td><i>(variable PVT and coning only)</i>
These fields are used to specify the depth of the top and bottom of the perforations for this layer. The values are only needed for Variable PVT (where it affects the PVT of the fluid produced from the layer) and the water and gas coning models (where the well position relative to the fluid contacts affects the magnitude of the coning)</td></tr>
<tr><td>Start Production</td><td>These fields are used for water coning only. They are used to define the history production for this layer, up to the start of the prediction calculation</td></tr>
</table>

History Oil Production History Water Production	
Production Schedule	This is only available if the 'Production Allocation' tool is in use. Click on the edit button to enter a production schedule. A production schedule is not absolutely necessary. If no schedule is entered then the layer will produce/ inject at all times

Well Control Fields

See Well Control Fields for more information.

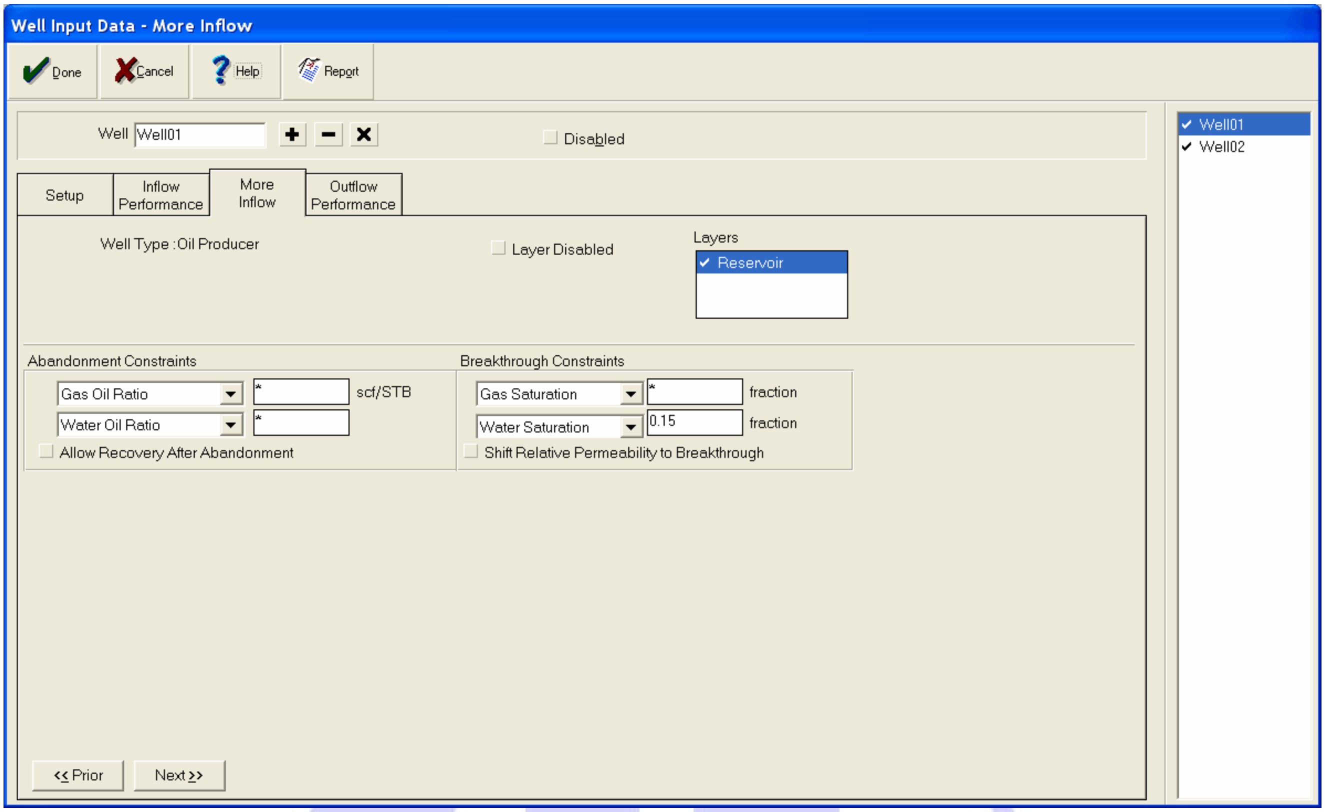
Command Buttons

Report	Allows output of a listing of the inflow and outflow performance for the current well
Calc	Calculates IPRs and TPCs intersection on test points provided by the user. (Not available for production allocation)
Match IPR	This option can be used to match the current IPR to one or more sets of well test data
Plot	Displays a graph of the in-flow performance curves to check the quality and validity of the data
Match Coning	This button is only enabled if gas or water coning has been enabled. Click on this button if the water 307 or gas 305 coning is to be matched. It is recommended that the coning models are matched as neither model is predictive

2.4.6.7.3 More Well Inflow Performance

This data is used by the 'Production Prediction' part of the program. This dialogue box is used to define the properties and constraints of a well or group of wells, including the layer breakthrough and abandonment data.

Once the well type definitions are established, these definitions are used through the well schedule to drive the production prediction calculations



Well: Well01 ☐ Disabled

✓ Well01
✓ Well02

Well Type : Oil Producer

☐ Layer Disabled

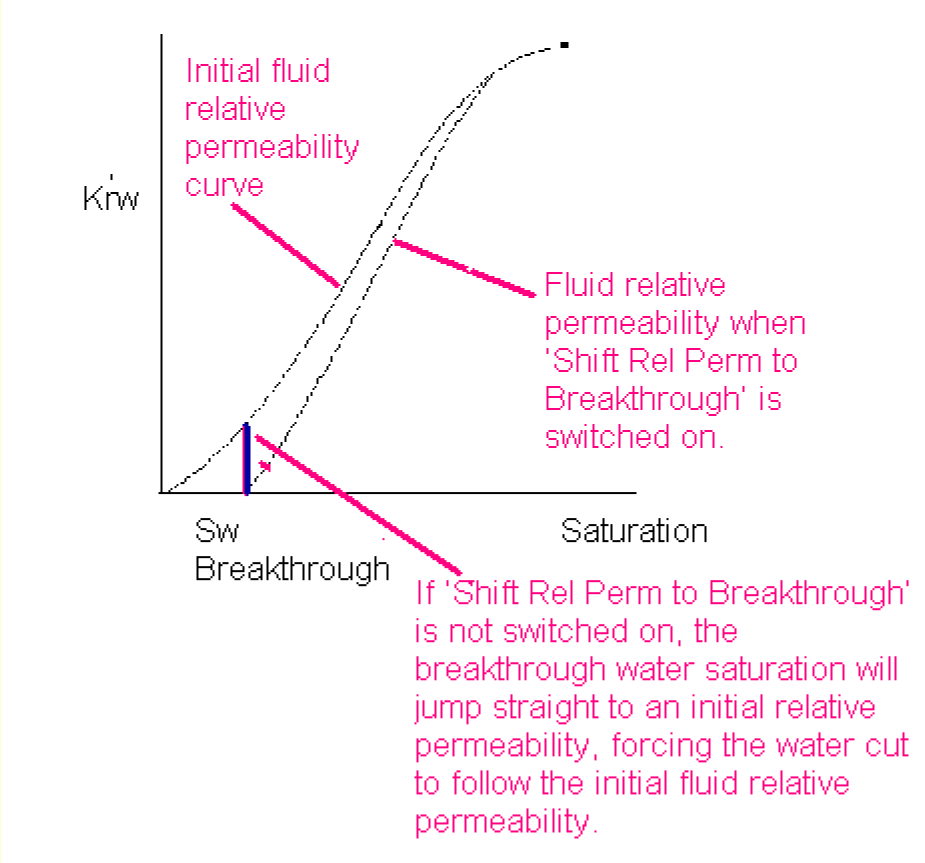
Layers
✓ Reservoir

Abandonment Constraints
Gas Oil Ratio: * scf/STB
Water Oil Ratio: *
☐ Allow Recovery After Abandonment

Breakthrough Constraints
Gas Saturation: * fraction
Water Saturation: 0.15 fraction
☐ Shift Relative Permeability to Breakthrough

Input Fields

Layers	For multi-layer wells, this list box is used to select which IPR is being edited in this data sheet
Layer Disabled	Set this button to 'on' if a layer is to be temporarily disabled (i.e. the tank connected to the current well) for the purposes of the calculation. This allows a layer to be removed from the calculation without deleting it permanently
Abandonment Constraints	The layer will be automatically shut-in if one of these values is exceeded. Leave blank if not applicable. Abandonment constraints can be specified in different ways e.g. water cut, water-oil contact, WOR. Select the appropriate expression from the combo-box. When the *Allow Recovery after Abandonment* flag is checked, the layer will resume production if the abandonment constraint is no longer satisfied. These constraints will be checked independently and in addition to any well abandonment constraints
Breakthrough Constraints	Breakthrough constraints are used to prevent the production of a particular phase until it reaches a particular saturation in the reservoir. This is a control over and above the relative permeabilities which have already been defined as residual saturations. Breakthrough constraints can be specified in different ways e.g. water cut, water-oil contact, WOR. Select the appropriate expression from the combo-box. If these are not in use for the model in question, they should be left blank.

	When a saturation is below the breakthrough constraint, the layer will not produce the fluid in question. When the saturation rises above the breakthrough constraint it will start to flow and the relative permeability will then be viewable as usual. This has the disadvantage that the relative permeability will suddenly jump from zero to the relative permeability at the breakthrough saturation which does not always represent the physical reality. There is a correction which can be applied to overcome the sudden jump is saturation in the form of the tab forShift Relative Permeability to Breakthrough '. In this case, the relative permeability is still zero when the saturation is below the breakthrough value. But after the breakthrough saturation it modifies the relative permeability curves:  Krw Initial fluid relative permeability curve Fluid relative permeability when 'Shift Rel Perm to Breakthrough' is switched on. Sw Breakthrough Saturation If 'Shift Rel Perm to Breakthrough' is not switched on, the breakthrough water saturation will jump straight to an initial relative permeability, forcing the water cut to follow the initial fluid relative permeability. This is done by a simple translation. It maintains the character of the relative permeability curve without the sudden large increase at breakthrough.
Gas Injection Recycling Saturations	This option is only available if 'General' material balance has been selected in the options dialogue. The main benefit is that production of injected gas can now be controlled by use of recirculation breakthroughs. Previously; gas production always contained a mixture of original gas and injected gas based on a volumetric average. Thus, as soon as gas injection started the

	produced CGR would start to drop. If no breakthroughs are entered, this will still be the case. However we are now able to enter a recirculation breakthrough. Whilst the gas injection saturation is below this breakthrough, none of the injection gas will be re-circulated. This will mean that injection gas will remain in the tank. The user may also enter a gas injection saturation at which full recirculation takes place. At this saturation, only injected gas is produced. Between the breakthrough and full recirculation saturation, a linear interpolation of the two boundary conditions is used

2.4.6.7.4 Inflow Performance (IPR) Models

This section explains the background behind the IPR models available in the IPR screen

Oil	
Straight Line IPR	The productivity index (or injectivity index for injectors) must always be entered. A straight line inflow model is used above the bubble point. The Vogel empirical solution is used below the bubble point. There are two further corrections which can be applied to the IPR calculations (for oil producers only):
Water Cut Correction	The Vogel part of the IPR model assumes a water cut of zero. However, in a prediction, **MBAL** will correct the Vogel part of the IPR for the current water cut. As the water cut increases, the Vogel curve progressively straightens resulting in increasing AOF. The correction will not have any effect on the straight-line part of the IPR. The plot of the IPR is normally plotted with a zero water cut. However if it is desired to check the shape of the IPR with a particular water cut, enter the value in the **Test Water Cut** field. The IPR plot will now be displayed with the correction for that water cut
Mobility Correction	A second assumption on the Straight-line + Vogel IPR model is that the mobility does not affect the IPR. However if the **P.I. Correction for Mobility** option is selected, **MBAL** will attempt to make corrections for change of fluid mobility using the relative permeability curves. If this option is used the **Test Reservoir Pressure** and **Test Water Cut** will require definition. The process is as follows: • Use the test water cut and the PVT model to calculate the downhole fractional flow Fw. • Calculate the water and oil saturations that give the Fw. Note we set Sg=0 as the IPR is already corrected for gas with the Vogel correction. • Calculate the relative oil and water permeabilities using the relative permeability curves and the oil and water saturations. • Calculate a test mobility from: $Mt = Kro/(\mu oBo) + Krw/(\mu wBw)$ The water and oil viscosities are calculated from the test reservoir pressures and the PVT. We should actually use the absolute oil and water relative permeabilities but since the only use of the total mobility

is when divided by mobility, the final results will be correct.

- Whenever an IPR calculation is done:
- Calculate the PVT properties using the current reservoir pressure and the PVT model.
- Calculate the downhole fractional flow from the current water cut.
- Calculate the water and oil saturations that give the Fw. Note we set Sg=0 as the IPR is already corrected for gas with the Vogel correction.
- Get the relative permeabilities for oil and water from the relative permeability curves.
- Calculate the current mobility M as shown above.
- Modify the PI using:
  PI = PIi * M/Mt

In the above method we do not account for the reduction in oil mobility due to any increase in the gas saturation. When calculating the Sw and So for a particular Fw we set Sg=0.0.

If it is desired to take the effect of increasing gas saturation into account then select the **Correct Vogel for GOR** option. It will also be necessary to enter a **Test GOR** - this is a produced GOR. The process will now be as follows:

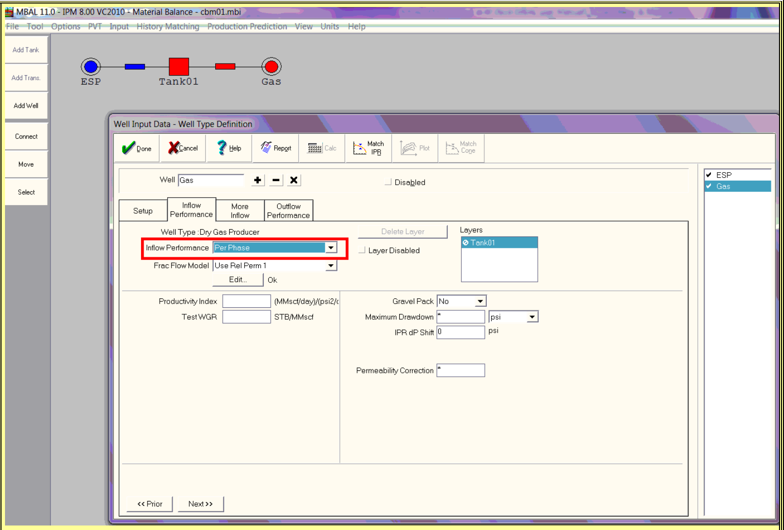
- Use the test water cut, test GOR and the PVT model to calculate the downhole fractional flows Fw and Fg.
- Calculate the gas, water and oil saturations that satisfy the Fw, Fg and So+Sw+Sg=1.0.
- Calculate the relative oil and water permeabilities using the relative permeability curves and the oil, gas and water saturations.
- Calculate a test mobility from:

Mt = Kro/(µoBo) + Krw/(µwBw)

- The water and oil viscosities are calculated from the test reservoir pressures and the PVT. We should actually use the absolute oil and water relative permeabilities but since the only use of the total mobility is when divided by mobility, the final results will be correct.
- Whenever an IPR calculation is carried out:
- Calculate the PVT properties using the current reservoir pressure and the PVT model.
- Calculate the downhole fractional flows Fw and Fg from the current water cut and produced GOR.
- Calculate the gas, water and oil saturations that satisfy the Fw, Fg and So+Sw+Sg=1.0.
- Get the relative permeabilities for oil and water from the relative permeability curves and the oil, gas and water saturations.
- Calculate the current mobility M as shown above.
- Modify the PI using:
  PI = PIi * M/Mt

Gas

Inflow Performance	**Forchheimer**	The Forchheimer equation expresses the inflow performance in terms of turbulent and non turbulent pressure drop coefficients expressed as: $(P_r^2 - P_{wf}^2) = aQ^2 + bQ$ In the inflow tab, **a** (the turbulent pressure drop) is the **Non Darcy** input field while **b** (the laminar pressure drop) is the **Darcy** input field
	C* and *n	This is the most common form of the back pressure equation: $Q = C(P_r^2 - P_w^2)^n$ ***C*** and ***n*** can be determined from a plot of Q versus (Pr2 - Pw2) on log-log paper. ***n*** is the inverse of the slope and varies between 1 for laminar flow and 0.5 for completely turbulent flow. This option requires direct entry of ***C*** and ***n*** in the inflow tab
	Forchheimer [Pseudo]	This is a variation of the Forchheimer equation using pseudo pressures. $m(P_r) - m(P_{wf}) = aQ^2 + bQ$ In the inflow tab, **a** (the turbulent pressure drop) is the **Non Darcy** input field. Similarly **b** (the laminar pressure drop) is the **Darcy** input file
	Per Phase	***New IPR method for IPM8.0*** Unlike other models where we calculate the major phase (e.g. liquid) from the IPR and then calculate the other phases (oil, gas and liquid) from the relative permebailities, this model calculates all three phases directly.


File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Add Tank
Add Trans.
Add Well
Connect
Move
Select
ESP
Tank01
Gas
Done
Cancel
Help
Report
Calc
Match IPR
Plot
Match Cone
Setup
Inflow Performance
More Inflow
Outflow Performance
Delete Layer
Edit...
<< Prior
Next >>
☑ ESP
☑ Gas

MBAL 11.0 - IPM 8.00 VC2010 - Material Balance - cbm01.mbi

Well Input Data - Well Type Definition

Well: Gas

☐ Disabled

Well Type :Dry Gas Producer

Inflow Performance: Per Phase

Frac Flow Model: Use Rel Perm 1

Ok

Layers: Tank01

☐ Layer Disabled

Productivity Index: (MMscf/day)/(psi2/c

Test WGR: STB/MMscf

Gravel Pack: No

Maximum Drawdown: * psi

IPR dP Shift: 0 psi

Permeability Correction: *

However we still use the rel perms to calculate the K_rs used in the new equations.

The three equations are:-

$$Q_w = \frac{kk_{rw}hdP}{141.2U_wB_w\left[ln\frac{r_e}{r_w} - \frac{3}{4} + S\right]}$$

$$Q_o = \frac{kk_{ro}hdP}{141.2U_oB_o\left[ln\frac{r_e}{r_w} - \frac{3}{4} + S\right]}$$

$$Q_g = \frac{kk_{rg}hdm(P)}{1442T\left[ln\frac{r_e}{r_w} - \frac{3}{4} + S\right]}$$

Rather than enter all the underlying parameters we enter the PI of the dominant phase at test conditions.

So if we have a water well we enter the PI of the water at the test conditions i.e. Qw/dP. We assume the water saturation is at a maximum so Krw=Water End Point. With the Uw and Bw calculated at test conditions we can then calculate the term common to all three equations i.e.

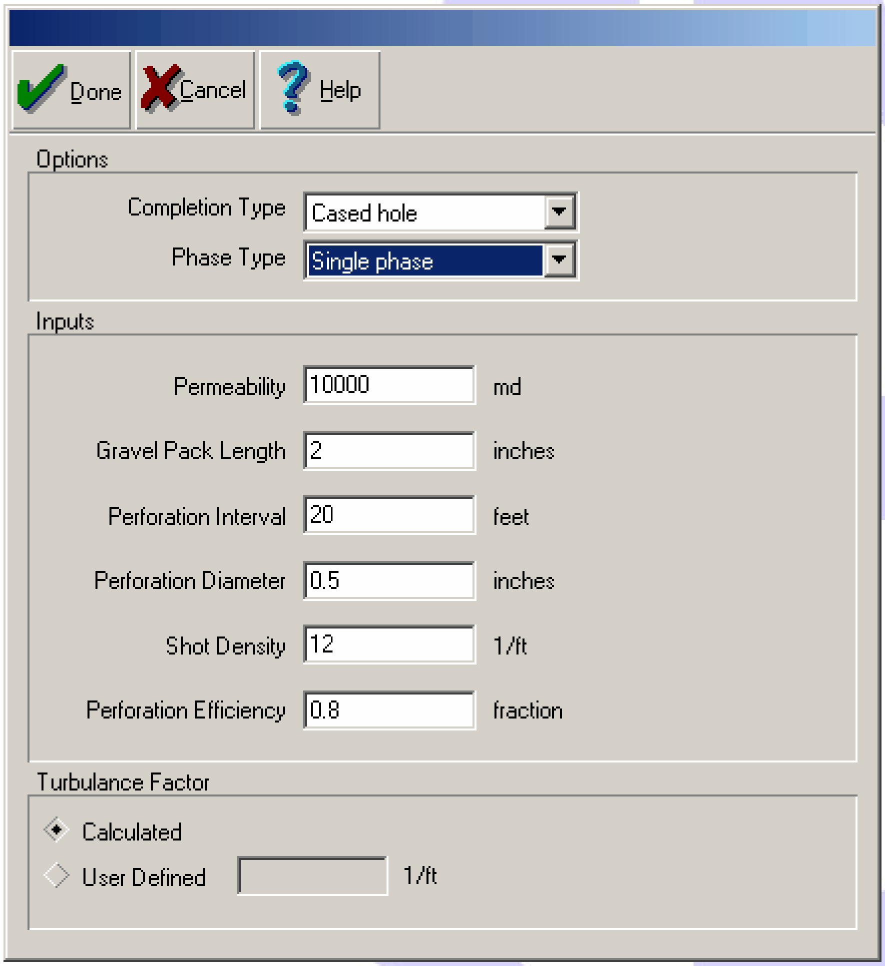
	$\frac{kh}{\left[ln\frac{r_e}{r_w}-\frac{3}{4}+S\right]}$ Then every time we need to calculate the IPR we use the common term above plus the fluid properties and K_rs at the current conditions to calculate all three phases. • If it is an oil well we enter the PI of the oil at test conditions and then follow the same logic as for water. • If it is a gas well we enter the PI of gas at test conditions defined by Q/dM(p). We then get the common term using the Krg at maximum Sg. Then follow the same method as for oil and water. ***Note*** that this method gives phase ratios that are rate dependant. However often in **GAP** or **MBAL** we need to have an IPR that reflects a fixed WGR/GOR etc. In this case we generate an IPR table where we adjust the saturations (and therefore the Krs) for each FBHP to ensure that the phase ratios are respected. So each FBHP point will have different saturations.
Mobility Correction	An assumption in the gas IPR models is that the mobility does not affect the IPR. However if the **P.I. Correction for Mobility** option is selected, **MBAL** will attempt to make corrections for change of fluid mobility using the relative permeability curves. If this option is used, the **Test Reservoir Pressure, WGR** and **CGR** will need to be entered: The process is as follows: • Use the test WGR, CGR and the PVT model to calculate the downhole fractional flows Fw and Fo. • Calculate the gas, water and oil saturations that satisfy the Fw, Fo and So+Sw+Sg=1.0. • Calculate the relative gas permeability using the relative permeability curves and the oil, gas and water saturations. • Calculate a test mobility from: For Forchheimer : Mt = Krg/(µg.Z) For Pseudo-Forchheimer : Mt = Krg For C&N : Mt = Krg/(µg.Bg) The gas viscosity, Bo and Z factor are calculated from the test reservoir pressures and the PVT. We should actually use the absolute gas relative

	permeability but since the only use of the total mobility is when divided by mobility, the final results will be correct. • Whenever an IPR is calculated: • Calculate the PVT properties using the current reservoir pressure and the PVT model. • Calculate the downhole fractional flows Fw and Fo from the current produced WGR and GOR. • Calculate the gas, water and oil saturations that satisfy the Fw, Fg and So+Sw+Sg=1.0. • Get the relative permeability for gas from the relative permeability curves and the oil, gas and water saturations. • Calculate the current mobility M as shown above. • Modify the IPR inputs using: • For Forchheimer and pseudo-Forchheimer a = a / (M/Mt) b = b / (M/Mt) • For C&N C = C * (M/Mt) Note: For gas tanks, the oil saturation is always zero. So we do not need to enter a test CGR and the Fo is always zero
Mobility Correction for Relative Permeabilities	Some of the above corrections use a set of relative permeability curves. By default the relative permeability curves used will be associated tank curves. However there are two other rel perms associated with the layer which may be used for the mobility corrections. In this case select Rel Perm 1 or Rel Perm 2 for the **Mobility Corr Rel Perms** and click the 'Edit' button to enter/ edit the relative permeability curves
Crossflow Injectivity Index	This field is only accessible if the multi-tank option is in use for producer wells. Normally if crossflow occurs, the IPR function is extrapolated for negative rates. This can cause stability problems as the IPR can be very flat due to the resulting negative rate (particularly for gas wells). This field can be used to define a different IPR for negative rates. This can then be used to reduce the injectivity of a layer and thus give better stability to cross-flow. For oil and water wells, the crossflow injectivity index is the same as the productivity index. For Forchheimer gas wells, the crossflow injectivity index is the same as the Darcy field. The Non Darcy value is set to zero for negative rates. For C&n gas wells, the crossflow injectivity index is the same as the C value. The n value is set to 1.0 for negative rates. If a crossflow injectivity index is not to be modelled (continue extrapolating

	the normal IPR) then enter an '*' in this field
Gravel Pack Section	• In previous versions of **IPM**, the gravel pack calculations were embedded in the lift curves as an extra pressure drop. This is because only ***PROSPER*** was able to calculate the Gravel Pack DP and the only way to transfer these calculations to the other program was via the lift curves. This has now changed to reflect the gravel pack calculations on the IPR in **MBAL** (and **GAP**). This model is explained in more detail in the dedicated Gravel Pack Model description that follows

2.4.6.7.5 Gravel Pack Model

The gravel pack model can be accessed from the well IPR screen by clicking the "Edit" button on the gravel pack section. The following screen will appear:



Options

Completion Type: Cased hole

Phase Type: Single phase

Inputs

Permeability: 10000 md

Gravel Pack Length: 2 inches

Perforation Interval: 20 feet

Perforation Diameter: 0.5 inches

Shot Density: 12 1/ft

Perforation Efficiency: 0.8 fraction

Turbulance Factor

● Calculated

○ User Defined 1/ft

There are choices for cased or open hole completions as well as single or multiphase calculations. The basis of the model is shown below:

If the non-Darcy factor (Beta) has not been entered, it will be calculated using:

$$\beta = \frac{1.47 \times 10^{7}}{K^{0.55}}$$

Next calculate the area (A).

For cased hole, A is calculated using:

$$A = \frac{3.14\left(P_{diameter} \big/ 12\right)^{2} S_{pf}\, P_{eff}\, P_{\text{int}}}{4}$$

For open hole we use:

$$A = 6.28\, R_{w} P_{\text{int}}$$

For oil single phase we simply use the density, viscosity and Bo of the oil at the reservoir pressure.

For oil multiphase: the oil, gas and water properties at the sand face pressure are calculated, followed by the calculation of an effective density, viscosity and Bo from the average of the three phases weighted by the downhole free production calculated from the GOR and Water Cut.

Finally the DP is calculated as follows:

$$a = \frac{9.08 \times 10^{-13}\, \beta B^{2} \rho L}{12\, A^{2}}$$

$$b = \frac{\mu B L}{12 \times 1.127 \times 10^{-3}\, K A}$$

$$dP = aQ^2 + bQ$$

For gas, the DP is calculated using:

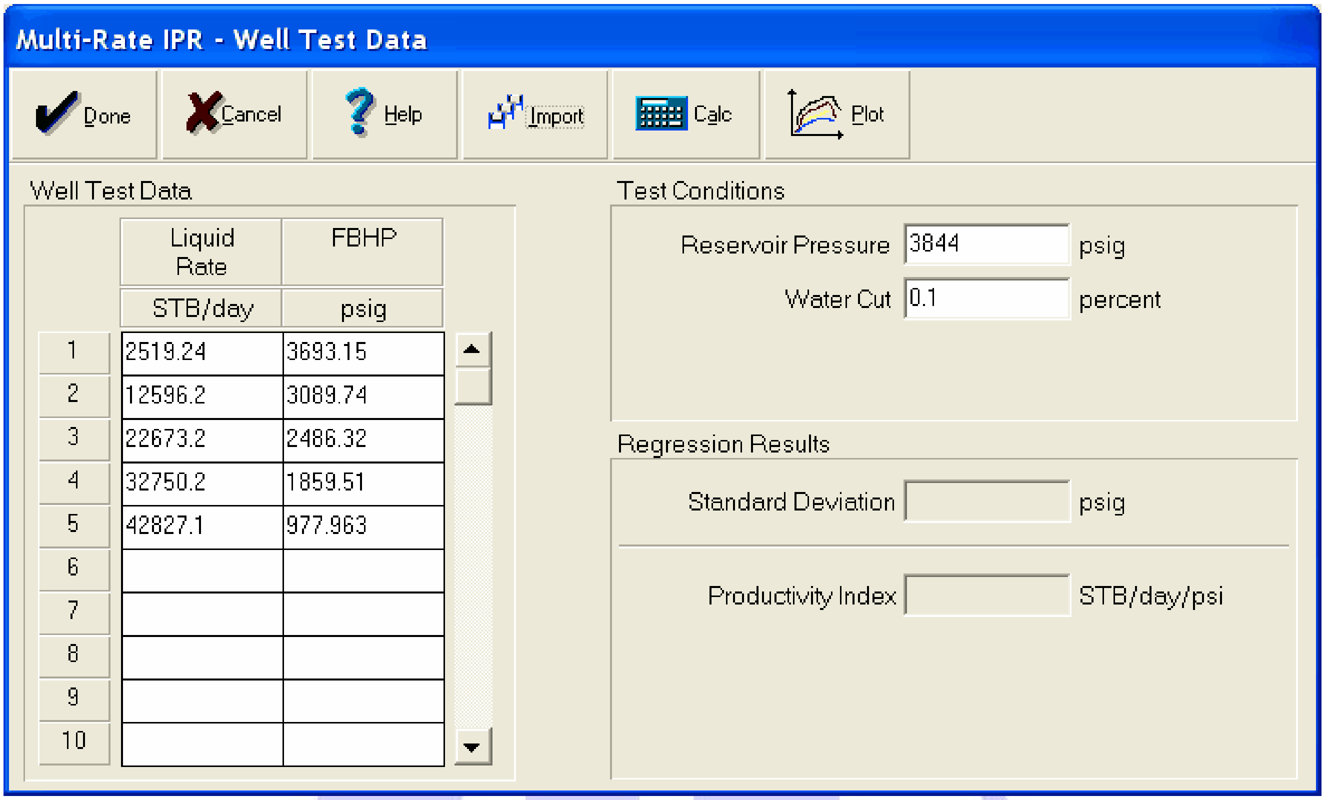
$$a = \frac{1.247 \times 10^{-10} \beta \gamma_g (T + 460.0) ZL}{12 A^2}$$

$$b = \frac{8930 \mu_g (T + 460.0) ZL}{12 KA}$$

$$dP = P_{sandface} - \sqrt{P_{sandface}^2 - \left(aQ^2 + bQ\right)}$$

2.4.6.7.6 Multirate Inflow Performance

If one or several well test data are available, the IPR parameters can be regressed upon to fit the observed rate and pressures. To access the 'Multirate IPR' screen click **Match IPR** in the 'Inflow Performance' screen above. A screen, as seen below will appear:



Well Test Data

	Liquid Rate	FBHP
	STB/day	psig
1	2519.24	3693.15
2	12596.2	3089.74
3	22673.2	2486.32
4	32750.2	1859.51
5	42827.1	977.963
6		
7		
8		
9		
10		

Test Conditions

Reservoir Pressure 3844 psig

Water Cut 0.1 percent

Regression Results

Standard Deviation psig

Productivity Index STB/day/psi

➡ **Before entering data in this table (a time consuming exercise), please note that well test data can be imported from various sources. The screen is primarily designed to work by importing *.MIP files from PROSPER, where the full IPR can be studied in detail.**

Input Fields

Test Reservoir Pressure	Define the reservoir average pressure at the time of the well test
Water Cut	(Oil only) Define the water cut at the time of the well test
Well Test Data	Enter all the rates and flowing bottom hole pressures available. See Table Data Entry for more information on entering the well test data

Regression Results

After selecting 'Calc', the results will be shown in the following fields

Standard Deviation	Displays the standard deviation It will also display the IPR parameters for the current model (e.g.

	Productivity Index, Non-Darcy) with the new regressed values

Click **Done** to keep the regressed IPR parameters or **Cancel** to ignore the calculation.

Command Buttons

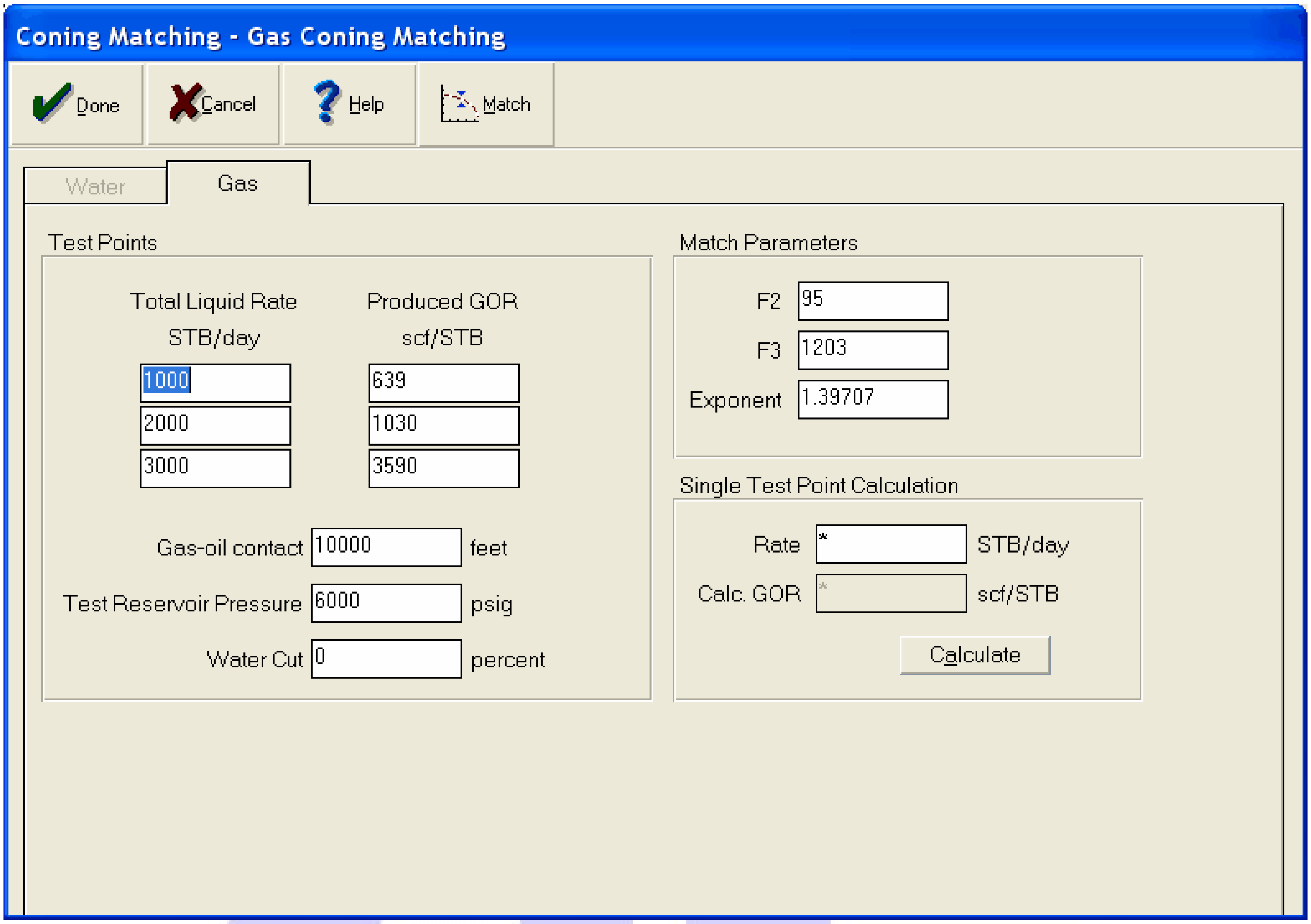
Import	This displays a dialogue which can be used to import the well test data from a **PROSPER** (*.MIP) file or an ASCII file. For an ASCII file, a filter will need to be created to define the columns in the file and how they relate to the **MBAL** data (or use a stored filter)
Calc	Click this button to start the regression. It will only take a few seconds
Plot	Click this button to display a plot of the IPR with the regressed parameters and the test data to test the validity of the match

2.4.6.7.7 Gas and Water Coning Matching

This dialogue is used to match the gas and water coning model. There are two tabs, one for gas and one for water. If either of the tabs is disabled, then the coning for that fluid is not enabled.

2.4.6.7.7.1 Gas Coning Matching

This model is not a predictive model so it should not be used unless matched to test data. Up to three test data points can be matched. The test points should be from a multi-rate test i.e. at the same tank conditions. It is also possible to directly edit the match parameters. See reference 32 or Appendix B for an interpretation of the match parameters.



Test Points

Total Liquid Rate STB/day	Produced GOR scf/STB
1000	639
2000	1030
3000	3590

Gas-oil contact 10000 feet

Test Reservoir Pressure 6000 psig

Water Cut 0 percent

Match Parameters

F2 95

F3 1203

Exponent 1.39707

Single Test Point Calculation

Rate * STB/day

Calc. GOR * scf/STB

Input Fields

Total Liquid Rate	Enter the water plus oil rate for each test point
Produced GOR	Enter the produced GOR for each test point
Gas-oil contact	The position of the gas oil contact at the time of the multirate test
Test Reservoir Pressure	The tank pressure at the time of the multirate test
Water cut	The water cut at the time of the multirate test
F2	First matching parameter
F3	Second matching parameter
Exponent	Third matching parameter

Enter the input fields in the **Test Points** section of the dialogue and then click **Calc** to calculate the match parameters that best fit the test data.

The test points should be from a multirate test i.e. at the same tank conditions. It is also possible to directly edit the match parameters. See **Urbanczyk, C.H. and Wattenbarger, R.A.: "Optimization of Well Rates under Gas Coning Conditions," SPE Advanced Technology Series, Vol. 2, No. 2.** for an interpretation of the match parameters.

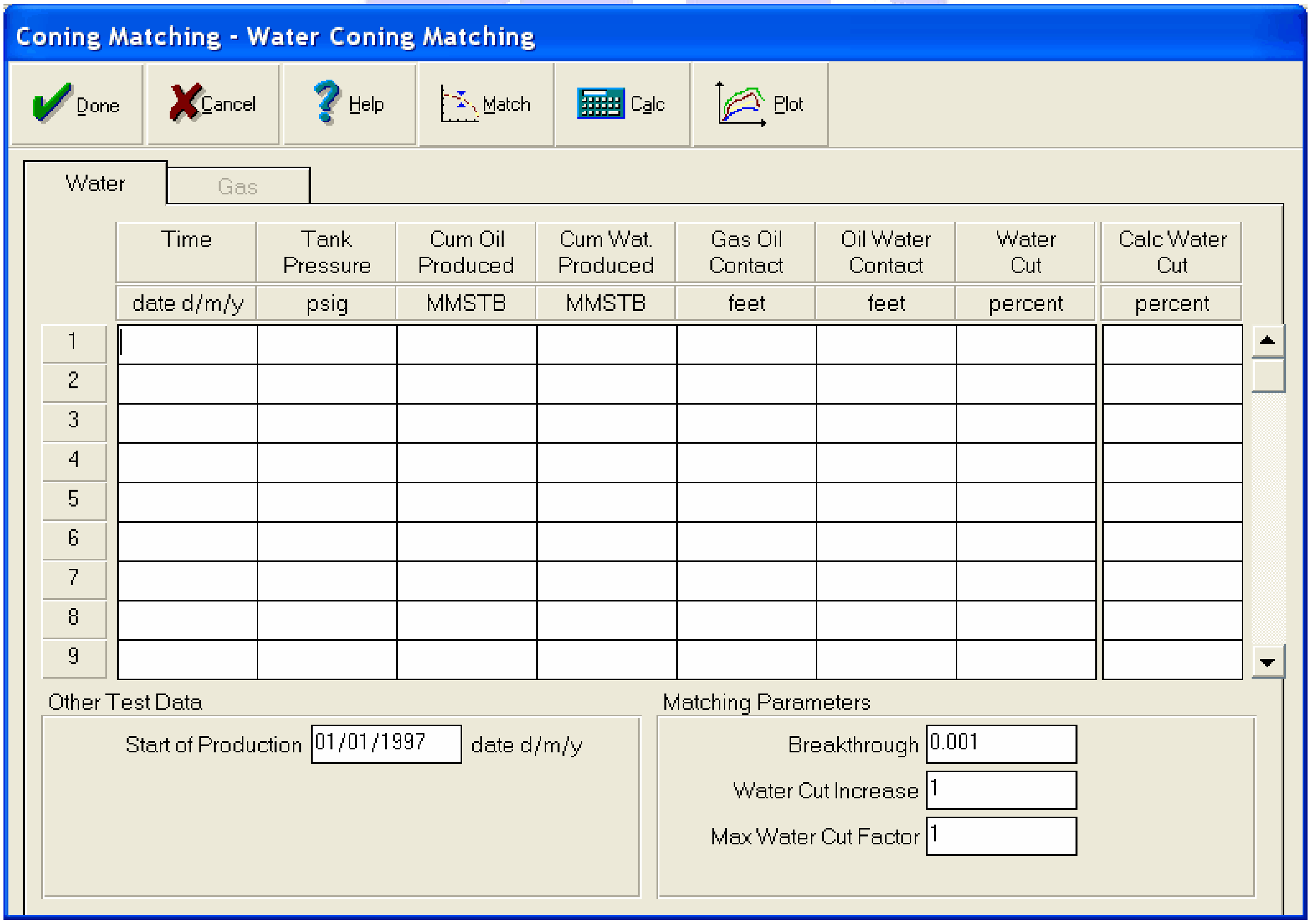
If only one test point is entered, only the **F3** tuning parameter is matched. If two or three test points are entered, only the **F3** and **Exponent** tuning parameters are matched. If desired, the unmatched tuning parameters can be edited directly by the user.

It is also possible to calculate the produced GOR for a single liquid rate in **the Single Test Point Calculation** Panel. Enter the rate in the **Rate** field and then click the **Calculate** button. The produced GOR for that entered rate will be displayed in the **Calc. GOR** field.

2.4.6.7.7.2 Water Coning Matching

This dialogue is used to match the water coning model to any number of test data points. This is not a predictive model so should only be used if tuned to test data. The test points should be from historical data i.e. from different times.

The method is based on the paper by "Bournazel-Jeanson, Society of Petroleum Engineers of AIME, 1971" although many modifications have been made to handle non-constant rates.



	Time	Tank Pressure	Cum Oil Produced	Cum Wat. Produced	Gas Oil Contact	Oil Water Contact	Water Cut	Calc Water Cut
	date d/m/y	psig	MMSTB	MMSTB	feet	feet	percent	percent
1								
2								
3								
4								
5								
6								
7								
8								
9								

Other Test Data

Start of Production 01/01/1997 date d/m/y

Matching Parameters

Breakthrough 0.001

Water Cut Increase 1

Max Water Cut Factor 1

The time to breakthrough is proportional to the rate. For low rates the breakthrough may never occur. After breakthrough the WC develops roughly proportionally to the log of the Np, to a maximum water cut.

The matching parameters are:

Breakthrough	Linear multiplier of the time to water breakthrough
Water Cut Increase	After breakthrough the water cut develops proportionally to the log of the Np. This factor is a linear multiplier of the water cut development
Maximum Water Cut Factor	The maximum water cut is defined by the maximum Fw = water mobility / (water mobility + oil mobility). This factor is a linear multiplier of the maximum water cut

Enter the test points in the dialogue and the time of start of production.

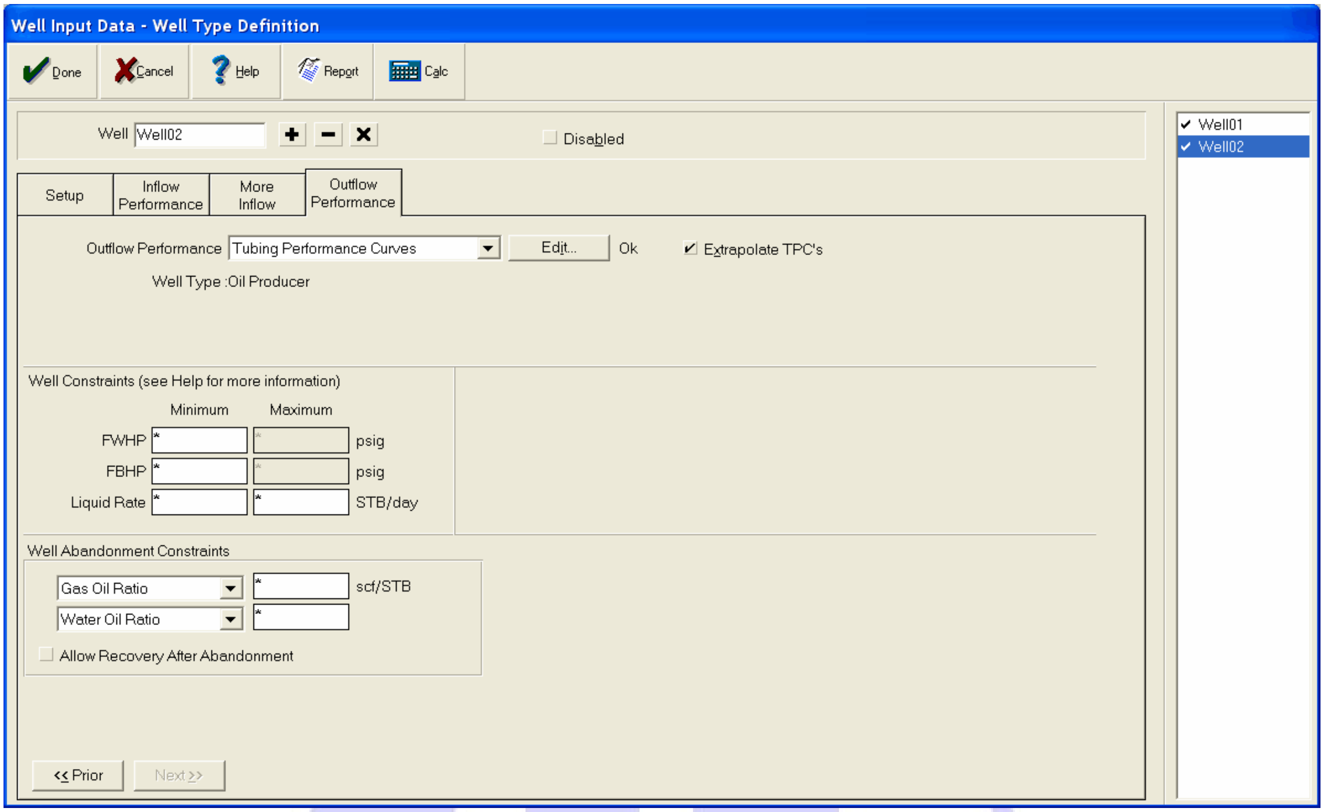
Automatic Matching	Click 'Match' to regress on the match parameters that best fit the test data. After matching the data, ***MBAL*** will automatically calculate the predicted WC for each data point and display the value in the 'Calculated Water Cut' column in the table. This will allow assessment on the quality of the match to be carried out
Manual matching	The match parameters may also be edited manually and the clicking on the 'Calc' button will calculate the predicted WC for each data point (using the entered match parameters) and display the value in the 'Calculated Water Cut' column in the table

See Table Data Entry for more information on entering the water coning data.

2.4.6.7.8 Well Outflow Performance

This data is used by the 'Production Prediction' part of the program. This dialogue box is used to define the properties and constraints of the outflow performance of a well or group of wells. Once the well type definitions are established, these definitions (together with the inflow performance) are used through the well schedule to drive the production prediction calculations.

This tab is used to enter the outflow performance and the well constraints.



Well Input Data - Well Type Definition

Well: Well02

☐ Disabled

☑ Well01
☑ Well02

Outflow Performance: Tubing Performance Curves

Ok

☑ Extrapolate TPC's

Well Type :Oil Producer

Well Constraints (see Help for more information)

	Minimum	Maximum	
FWHP	*	*	psig
FBHP	*	*	psig
Liquid Rate	*	*	STB/day

Well Abandonment Constraints

Gas Oil Ratio	*	scf/STB
Water Oil Ratio	*	

☐ Allow Recovery After Abandonment

Input Fields

Outflow Performance	Defines the well FBHP (flowing bottom hole) constraints. Select the appropriate option from the list of constraints currently supported and click **Edit** to obtain access to the FBHP constraints dialogue box. The types available are: • **Constant FBHP** 311 • **Tubing performance curves (TPCs)** 312 • **Cullender - Smith** 315 **(gas and condensate only)** • **Witley** 317 **(gas and condensate only)** (See the section on "*Tubing performance curves* 311" for more information. The Cullender - Smith method is based on the method found in the paper by M. H. Cullender and R. V. Smith, *J. Pet. Tech.* (Dec. **1956**) pp 281-87.) ➲ **The option of 'Constant FBHP' should ONLY be us caution as it is a non-realistic representation of how the**
Extrapolate TPCs	This option can be used to extrapolate VLPs beyond the entered range. If this option is not selected, then the VLP will remain at its maximum/minimum value outside of its entered range.

	➲ **It is always recommended that VLPs are generated t range of rates (WHPs, GOR, GLR...) used by the pr calculations**
Minimum FBHP	The well is automatically shut-in if the FBHP falls below this value. The well can be re-started if the FBHP later exceeds this value, due to the start of water injection for example. Leave blank if not applicable
Maximum FBHP	The flow rate for injectors will be reduced to satisfy this constraint. Leave blank if not applicable. ➲ **This value is ignored for producing wells as there is n the rate. It is only respected for injectors where the w back to decrease the FBHP.**
Minimum Rate	The well is automatically shut-in if the calculated instantaneous rate falls below this value. The well may be re-started after a change in reservoir pressure due to, for example the start of water injection. Leave blank if not applicable
Maximum Rate	If the calculated flow rate exceeds this value, the instantaneous rate will be reduced to satisfy this constant. Leave blank if not applicable
Minimum FWHP	The well is automatically shut-in if the FWHP falls below this value. The well can be re-started if the FWHP later exceeds this value. Leave blank if not applicable
Maximum FWHP	The flow rate will be reduced to satisfy this constraint. Leave blank if not applicable
Operating Frequency	(**ESP Producer Wells Only**) If this well is an ESP well, the operating frequency of the pump in this field needs to be entered
PCP Pump Speed	(**PCP Producer Wells Only**) If this well is a PCP well, the PCP pump speed in this field needs to be entered
% Power Fluid	(**HSP Producer Wells Only**) If this well is a HSP well, the % power fluid in this field needs to be entered
Operating GLR Inj	(**Gas Lifted Wells Only**) If this well is a gas lifted well, the operating GLR needs to be entered. One can enter this value in two ways: **Operating GLR Inj** — Specify the gas lift GLR injected into the gas value does not include any gas produced fro

	Operating GLR Total	Specify the total GLR for the well. This includ gas injected into the well plus any GLR from
Abandonment Constraints	The well will automatically be shut-in if one of these values is exceeded. Leave blank if not applicable. Abandonment constraints can be specified different ways e.g. water cut, water-oil contact, WOR. Click the * button to select the appropriate expression. When the *Allow Recovery after Abandonment* flag is checked, the well will resume production if the abandonment constraint is no longer satisfied. For a well with more than one layer these constraints will be checked independently and in addition to any layer abandonment constraints	

Well Control Fields

See Well Control Fields for more information.

Command Buttons

Report	Allows output of a listing of the inflow and outflow performance for the current well
Calc	Displays the dialogue in which; tank pressures, manifold pressures and phase fractions can be entered and the operating point calculations can then be performed based on the current IPR and outflow performance to give a flowing bottom hole pressure and rate

2.4.6.7.9 Tubing Performance

This section describes how to model the performance of the well.

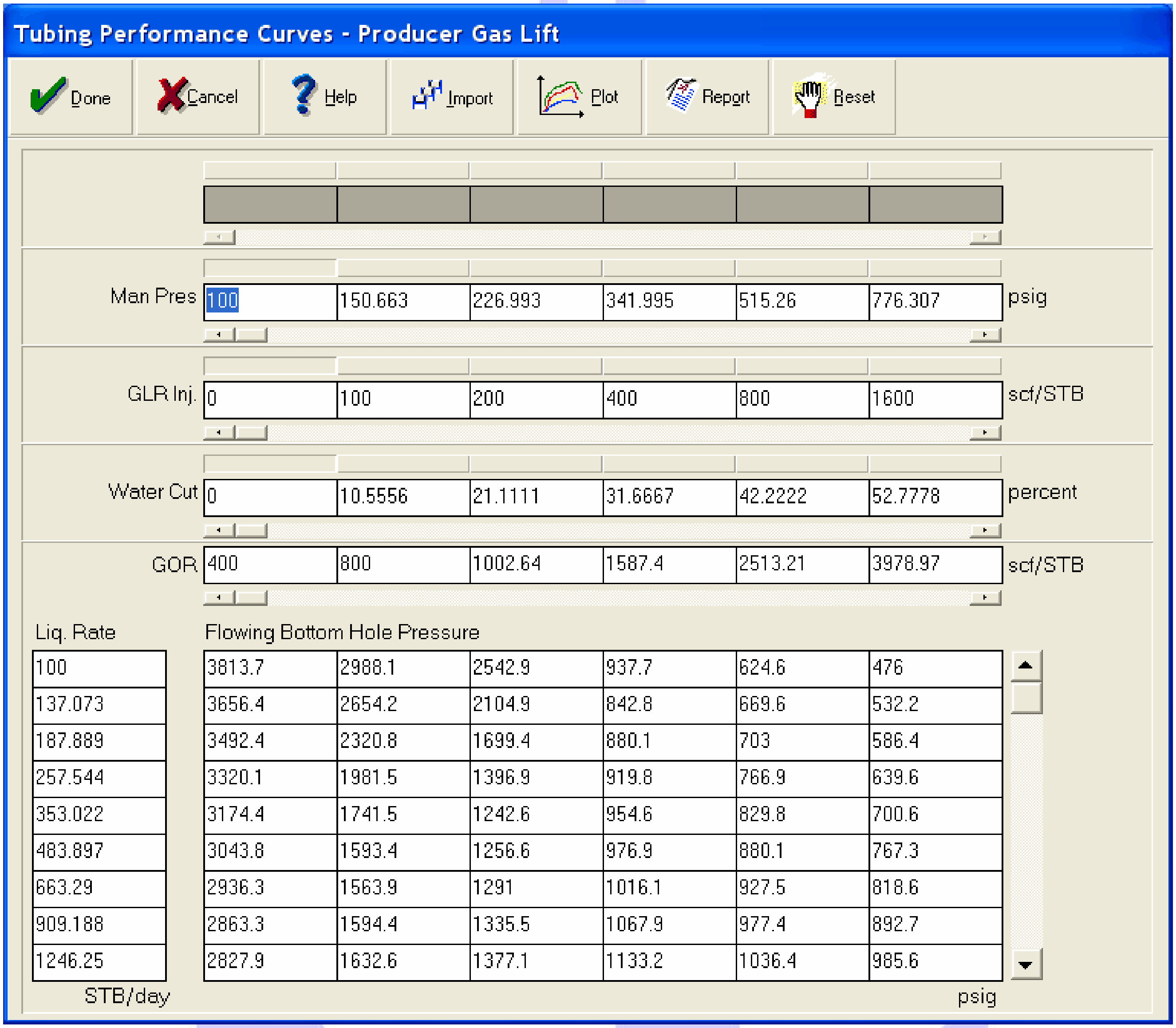
2.4.6.7.9.1 Constant Bottom Hole pressure

Using this option, the program will maintain the bottom hole flowing pressure constant throughout the prediction. This option can be used for a quick estimation of injectors' potential. It should not be used for options other than sucker rod pumped producers.

➡ **The option of Constant FBHP should ONLY be used with extreme caution. It is likely to give erroneous results for any constraints applied to the system.**

2.4.6.7.9.2 Tubing Performance Curves

The Tubing Performance Curve (TPC or VLP) dialogue box will appear different depending on the well type selected (i.e. Natural Flowing, Gas lifted, Injector, etc.). The example below describes one of the mor complicated TPC dialogue boxes: Gas Lifted Producer:



Man Pres	100	150.663	226.993	341.995	515.26	776.307	psig
GLR Inj.	0	100	200	400	800	1600	scf/STB
Water Cut	0	10.5556	21.1111	31.6667	42.2222	52.7778	percent
GOR	400	800	1002.64	1587.4	2513.21	3978.97	scf/STB

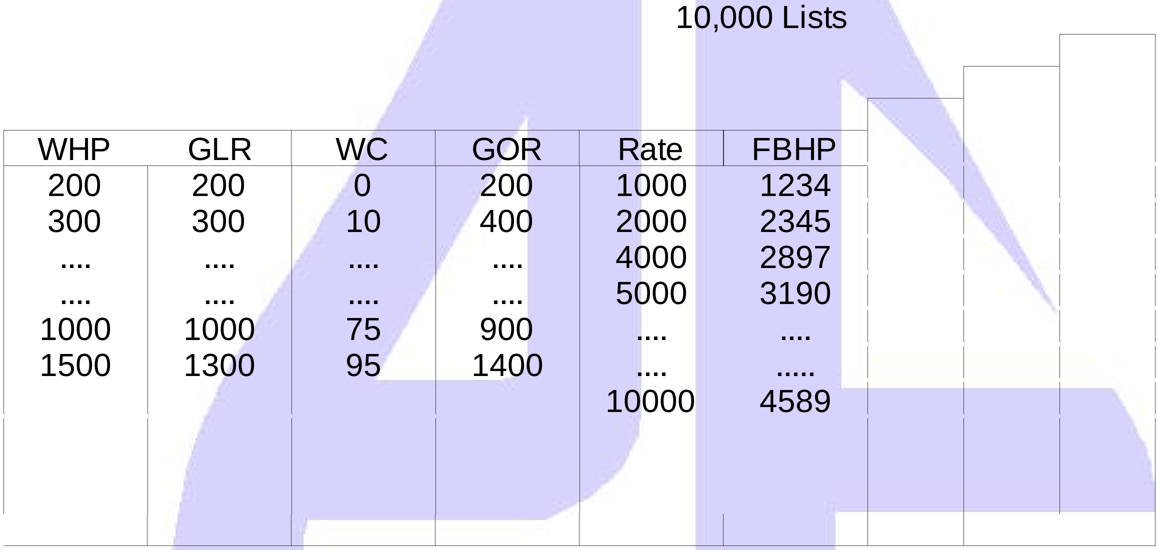
Liq. Rate	Flowing Bottom Hole Pressure					
100	3813.7	2988.1	2542.9	937.7	624.6	476
137.073	3656.4	2654.2	2104.9	842.8	669.6	532.2
187.889	3492.4	2320.8	1699.4	880.1	703	586.4
257.544	3320.1	1981.5	1396.9	919.8	766.9	639.6
353.022	3174.4	1741.5	1242.6	954.6	829.8	700.6
483.897	3043.8	1593.4	1256.6	976.9	880.1	767.3
663.29	2936.3	1563.9	1291	1016.1	927.5	818.6
909.188	2863.3	1594.4	1335.5	1067.9	977.4	892.7
1246.25	2827.9	1632.6	1377.1	1133.2	1036.4	985.6
STB/day						psig

In this particular example of a gas lifted well, the tubing performance curves table is a 5 dimensional array of FBHP versus WHP, GLR, WC, GOR and Rates, making altogether 200,000 (10*10*10*10*20) posseible FBHP entries. For each WHP, GLR, WC, GOR and Rates combination, there will be one bottom hole pressure.

WHP 1	GLR 1	WC 1	GOR 1	RATE 1	FBHP 1
WHP 1	GLR 2	WC 2	GOR 2	RATE 2	FBHP 2

...	...	...	...	...	...
WHP 1	GLR 1	WC 1	GOR 1	RATE 20	FBHP 20
WHP 1	GLR 2	WC 1	GOR 1	RATE 1	FBHP 21
...	...	...	...	...	...
WHP 1	GLR 2	WC 1	GOR 1	RATE 20	FBHP 40
WHP 1	GLR 2	WC 2	GOR 1	RATE 1	FBHP 41
...	...	...	...	...	...
WHP 1	GLR 2	WC 2	GOR 1	RATE 20	FBHP 60
...	...	...	...	...	...
WHP 10	GLR 10	WC 10	GOR 10	RATE 20	FBHP 200000

Altogether a total of 50000*5 values that have to be entered and stored. To minimise data entry, reduce the amount of memory space required and speed up the calculations, the tubing performance curves have been split into 6 tables, displayed as follows:


10,000 Lists

WHP	GLR	WC	GOR	Rate	FBHP
200	200	0	200	1000	1234
300	300	10	400	2000	2345
....	....	....	....	4000	2897
....	....	....	....	5000	3190
1000	1000	75	900	....	....
1500	1300	95	1400	....	.....
				10000	4589

These 6 tables comprise:

- 4 tables containing up to 10 values for WHP, GLR, WC and GOR,
- 1 table containing up to 20 rates,
- 1 2D table containing 10000 (10*10*10*10) lists of 20 FBHPs.

This means that the GLR, WC, GOR, and the Rates only need to be entered once. The FBHPs displayed on the screen are for a given WC, GLR and WHP combination. To display the VLPs for another combination of WCs, GLRs and WHPs, depress the table button above the WC, GLR and WHP values desired.

Enter data in a VLP table:

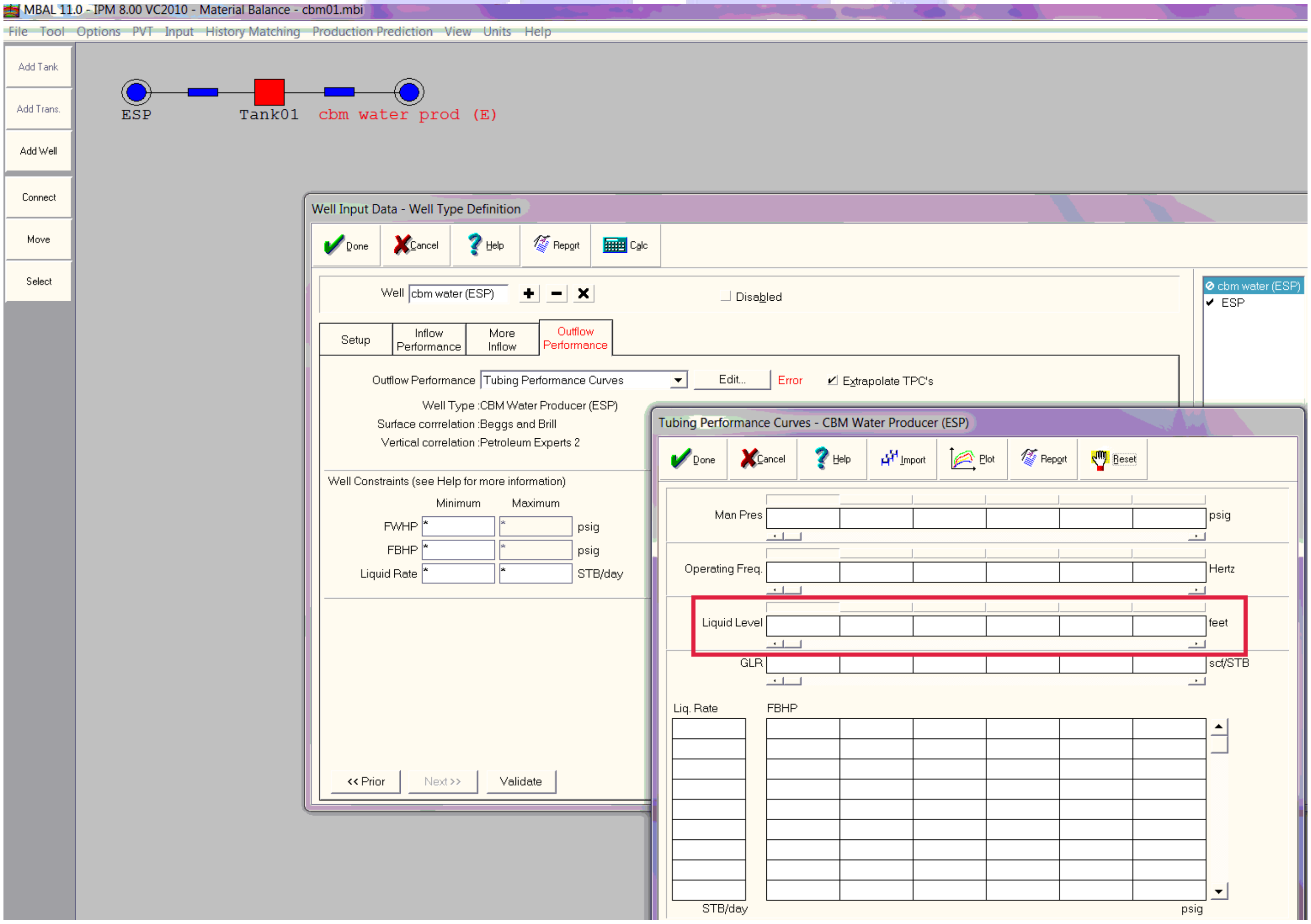
1. First enter up to 10 WHP values in the first (horizontal) table.
2. Next enter up to 10 GLR values in the second (horizontal) table.
3. Next enter up to 10 WC percentages in the third (horizontal) table.

4. Follow with the GORs (up to 10) in the fourth lower (horizontal) table
5. Then, enter up to 20 rates in the vertical table for this combination, using the scroll bar if necessary.
6. Fill in the FBHP table for the given rate and GOR, again using the scroll bar if necessary.
7. Select another combination of GLR, WC and WHP by depressing the buttons above the desired values. A new table of FBHP is displayed.
8. Repeat step 6, until all GLR, WC and WHP combinations are exhausted.

Lift Curves For CBM wells (New to IPM8.0)

For CBM water producers the lift curve format now includes liquid level (see screen shot below). The liquid level is then entered for the well.

For any ESP or PCP pumped well the lift curves can now have the casing gas rate as a calculated variable. The casing rate is then reported in the well results.

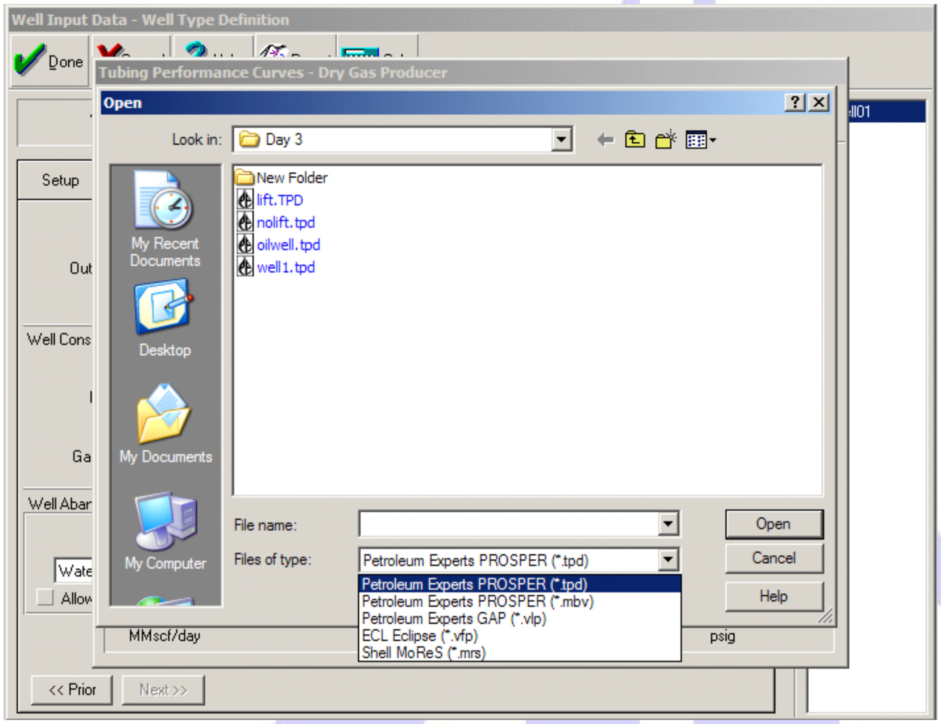

MBAL 11.0 - IPM 8.00 VC2010 - Material Balance - cbm01.mbi
File Tool Options PVT Input History Matching Production Prediction View Units Help
Add Tank
Add Trans.
Add Well
Connect
Move
Select
ESP
Tank01
cbm water prod (E)
Well Input Data - Well Type Definition
Done
Cancel
Help
Report
Calc
Disabled
Setup
Inflow Performance
More Inflow
Outflow Performance
Edit...
Error
Extrapolate TPC's
cbm water (ESP)
ESP
Well Constraints (see Help for more information)
Minimum
Maximum
FWHP
FBHP
Liquid Rate
psig
psig
STB/day
<< Prior
Next >>
Validate
Tubing Performance Curves - CBM Water Producer (ESP)
Done
Cancel
Help
Import
Plot
Report
Reset
Man Pres
psig
Operating Freq.
Hertz
Liquid Level
feet
GLR
scf/STB
Liq. Rate
FBHP
STB/day
psig

Well: cbm water (ESP)

Outflow Performance: Tubing Performance Curves

Well Type :CBM Water Producer (ESP)
Surface correlation :Beggs and Brill
Vertical correlation :Petroleum Experts 2

To import TPC data from another source, click the **Import** command. An import dialogue box is displayed prompting the user to select an import file to be read. Several file formats may are available:


Well Input Data - Well Type Definition
Done
Setup
Out
Well Cons
Ga
Well Abar
Wate
Allow
<< Prior
Next >>
Tubing Performance Curves - Dry Gas Producer
MMscf/day
psig
Open
Look in: Day 3
New Folder
lift.TPD
nolift.tpd
oilwell.tpd
well1.tpd
My Recent Documents
Desktop
My Documents
My Computer
File name:
Files of type: Petroleum Experts PROSPER (*.tpd)
Petroleum Experts PROSPER (*.tpd)
Petroleum Experts PROSPER (*.mbv)
Petroleum Experts GAP (*.vlp)
ECL Eclipse (*.vfp)
Shell MoReS (*.mrs)
Open
Cancel
Help

File Type	This field holds a list of import file types. **MBAL** currently recognises Petroleum Experts' .MBV and .TPD and GeoQuest ECLIPSE format lift curves. For information on opening a file, please refer to ; "*Using the* 30 **MBAL** 30 *application* 30". When the appropriate file has been selected, press ***OK***. This will open the file and reformat the data according to the type of file selected. The procedure displays an import information screen that gives brief details about the file being translated. The user will be informed when the translation is finished

2.4.6.7.9.3 Cullender Smith correlation

This correlation estimates the pressure drop in the tubing/annulus for a dry gas well. [Ref. Cullender, M.H. and Smith, R.V.: "Practical Solution of Gas-Flow Equations for Well and Pipelines with Large Temperature Gradients", Trans., AIME (1956)207.]

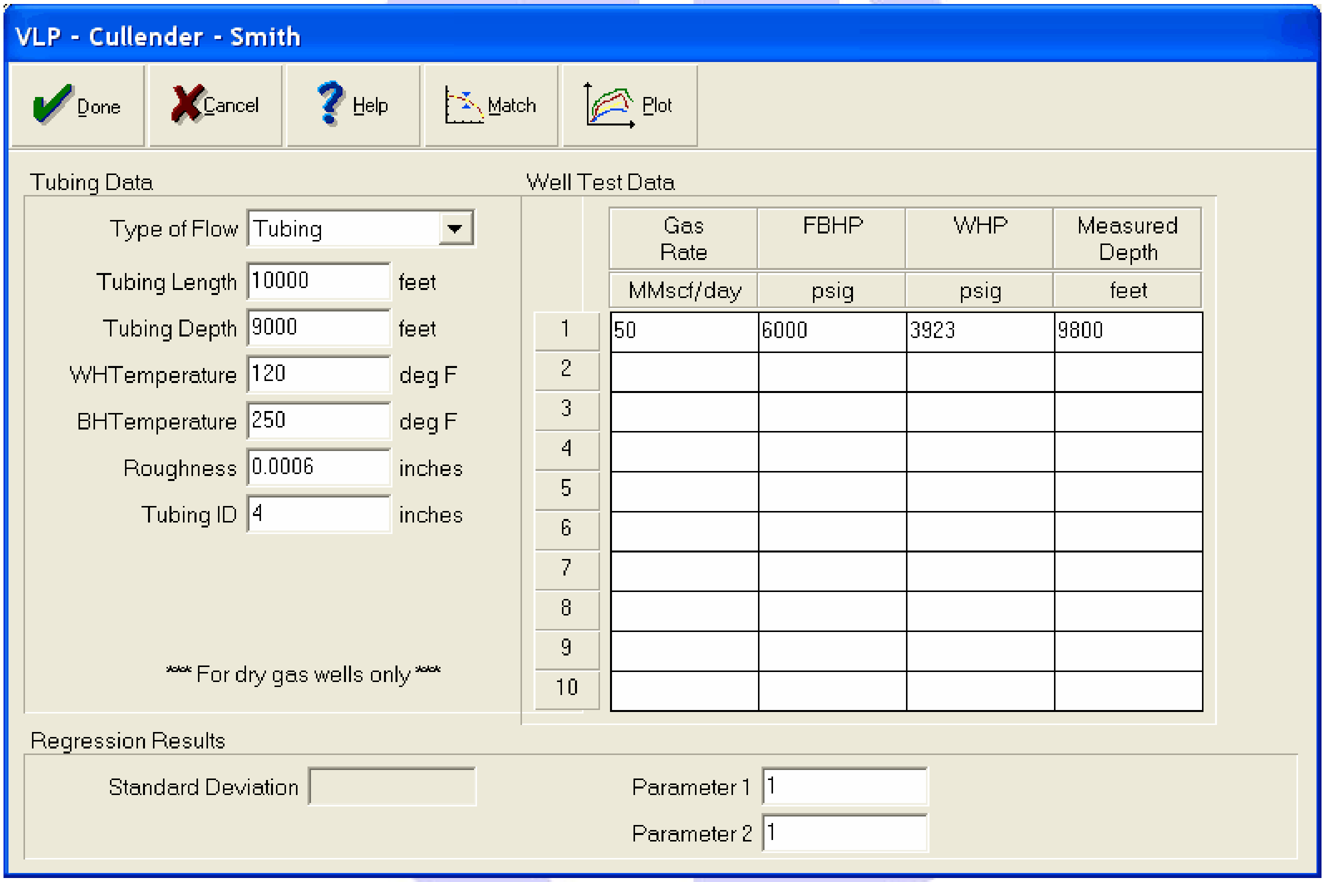
The correlation can be adjusted by entering well test data in the corresponding table and clicking the ***Match*** button. Two adjustment parameters are then displayed. These indicate the changes that have been applied to the gravity and friction terms respectively in which:

$$\frac{GH}{53.34} * C_0 = \int_{Ps}^{Pw} \frac{\left[\frac{p}{T * z}\right]}{1000 * (L/H) * (F_r * Q)^2 * C_1 + \left[\frac{p}{T * z}\right]^2} * dp$$

where:

G = gas gravity relative to air
L = length of pipe or tubing, ft
H = vertical elevation difference, ft
Q = flow rate in MMscf/D
z = Gas deviation factor
T = temperature, °R
d = inside diameter of the tubing, in.
Fr = friction factor.

C_0,C_1 are the matching parameters initially set to 1



Tubing Data

Type of Flow: Tubing
Tubing Length: 10000 feet
Tubing Depth: 9000 feet
WHTemperature: 120 deg F
BHTemperature: 250 deg F
Roughness: 0.0006 inches
Tubing ID: 4 inches

*** For dry gas wells only ***

Well Test Data

	Gas Rate	FBHP	WHP	Measured Depth
	MMscf/day	psig	psig	feet
1	50	6000	3923	9800
2				
3				
4				
5				
6				
7				
8				
9				
10				

Regression Results

Standard Deviation:
Parameter 1: 1
Parameter 2: 1

Input Fields

Type of Flow	Select 'Tubing' or 'Annular' flow

Tubing length	The measured length of the tubing
Tubing depth	The true vertical depth of the end of tubing. An average deviation is calculated from the length of the tubing
Wellhead Head Temperature	An estimate of the well head flowing temperature
Bottomhole Temperature	Temperature of the fluid at the bottomhole
Roughness	Average roughness of the tubing
Tubing ID	(tubing flow only) Inner diameter of the tubing
Tubing OD	(annular flow only) Outer diameter of the tubing
Casing ID	(annular flow only) Inner diameter of the casing

➡ **This correlation should only be used with dry gas wells. This option is significantly slower than the Tubing Performance Curves. If possible VLPs should be used rather than this correlation.**

2.4.6.7.9.4 Witley correlation

This correlation estimates the pressure drop in the tubing/annulus for a dry gas well. The correlation can be adjusted by entering well test data in the corresponding table and clicking the ***Match*** button. Three adjustment parameters are then displayed.

$$Qg^2 = (Ps^2 - CI * Pw^2) / (E * (CI - 1))$$

$$E = e^X$$

$$X = 0.006644 * (Z^2 * T^2 / D^{5.23}) * (XTUB / DEPTH) * DD * C1 + (C2 - 1) * 1e^{-7}$$

$$CI = 0.06844 * S * DEPTH / (Z * T) * C3$$

where:

Qg = total stream rate
Ps = Bottom hole flowing pressure
Pw = Well head flowing pressure
Z = Gas deviation factor @ T and P_w
T = Reservoir temperature
XTUB = tubing length
DEPTH = tubing vertical depth

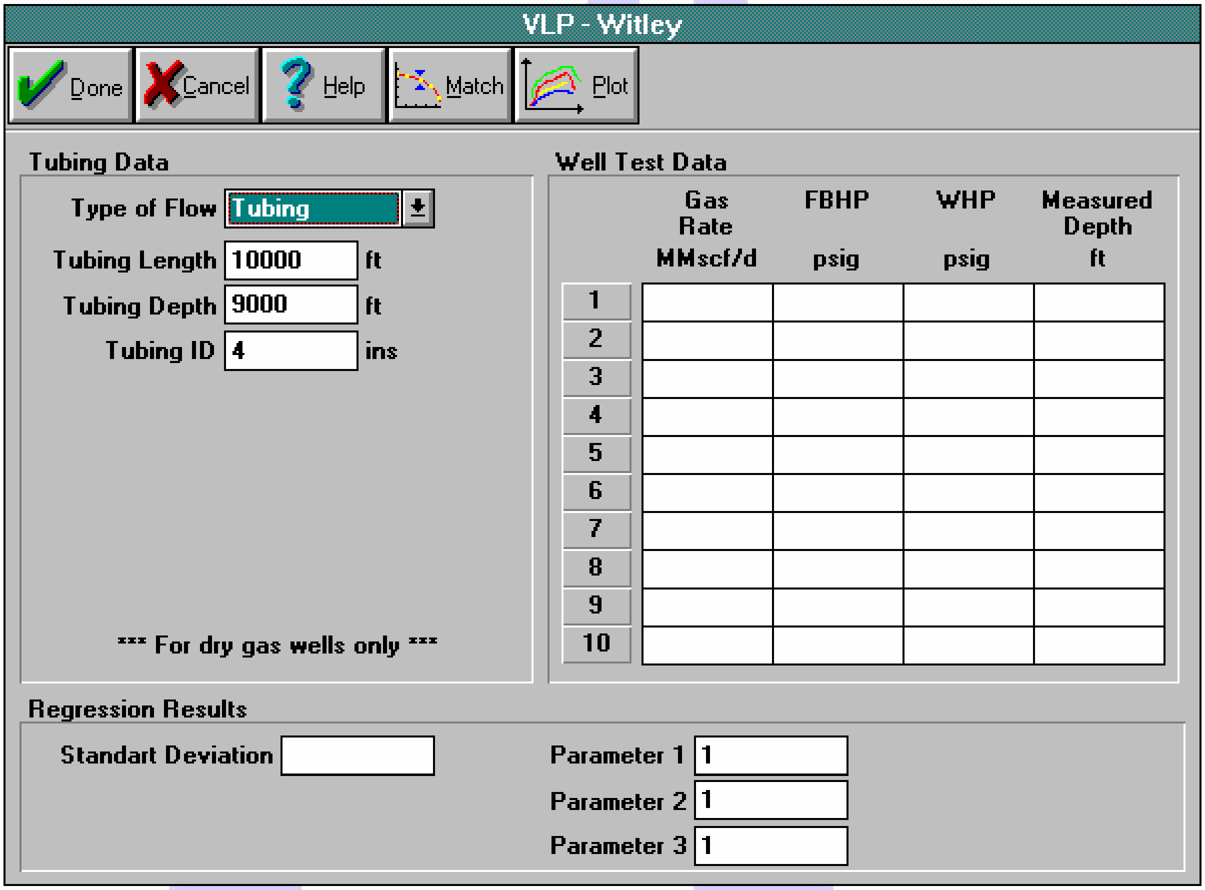
- For tubing flow

D = Tubing inner diameter
DD = 1

- For annular flow

D1 = Casing inner diameter
D2 = Casing outer diameter
D = D1+D2
DD = [(D1+D2)/(D1-D2)]3

C1,C2,C3 are the matching parameters initially set to 1.



Tubing Data

Type of Flow: Tubing
Tubing Length: 10000 ft
Tubing Depth: 9000 ft
Tubing ID: 4 ins

*** For dry gas wells only ***

Well Test Data

	Gas Rate MMscf/d	FBHP psig	WHP psig	Measured Depth ft
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Regression Results

Standart Deviation:
Parameter 1: 1
Parameter 2: 1
Parameter 3: 1

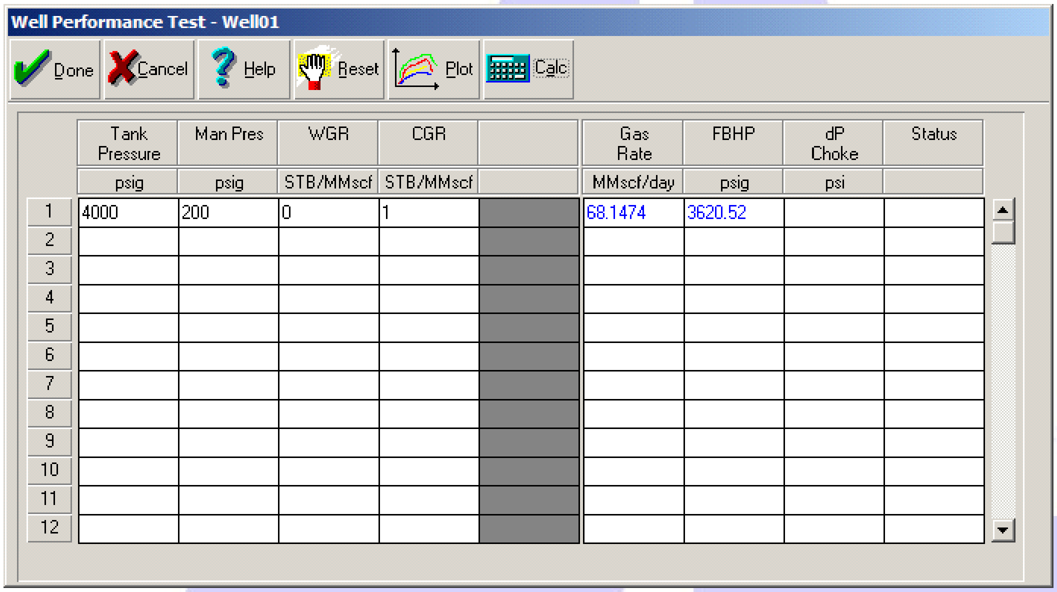
Input Fields

Type of Flow	Select 'Tubing' or 'Annular' flow
Tubing length	The measured length of the tubing
Tubing depth	The true vertical depth of the end of tubing. An average deviation is calculated from the length of the tubing
Tubing ID	*(tubing flowonly)* Inner diameter of the tubing
Tubing OD	*(annular flowonly)* Outer diameter of the tubing
Casing ID	*(annular flowonly)* Inner diameter of the casing

This correlation should only be used with **dry gas wells.** This option is **significantly slower** than the Tubing Performance Curves. If possible VLPs should be used rather than this correlation.

2.4.6.8 Testing the Well Performance

This dialogue box lets the user can test the solution points of the IPRs and VLPs. This 'local' calculation does not affect the rest of the prediction. It is only provided to check the validity of the IPR / VLP combinations or to troubleshoot certain situations.



	Tank Pressure psig	Man Pres psig	WGR STB/MMscf	CGR STB/MMscf		Gas Rate MMscf/day	FBHP psig	dP Choke psi	Status
1	4000	200	0	1		68.1474	3620.52		
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									

Input Fields

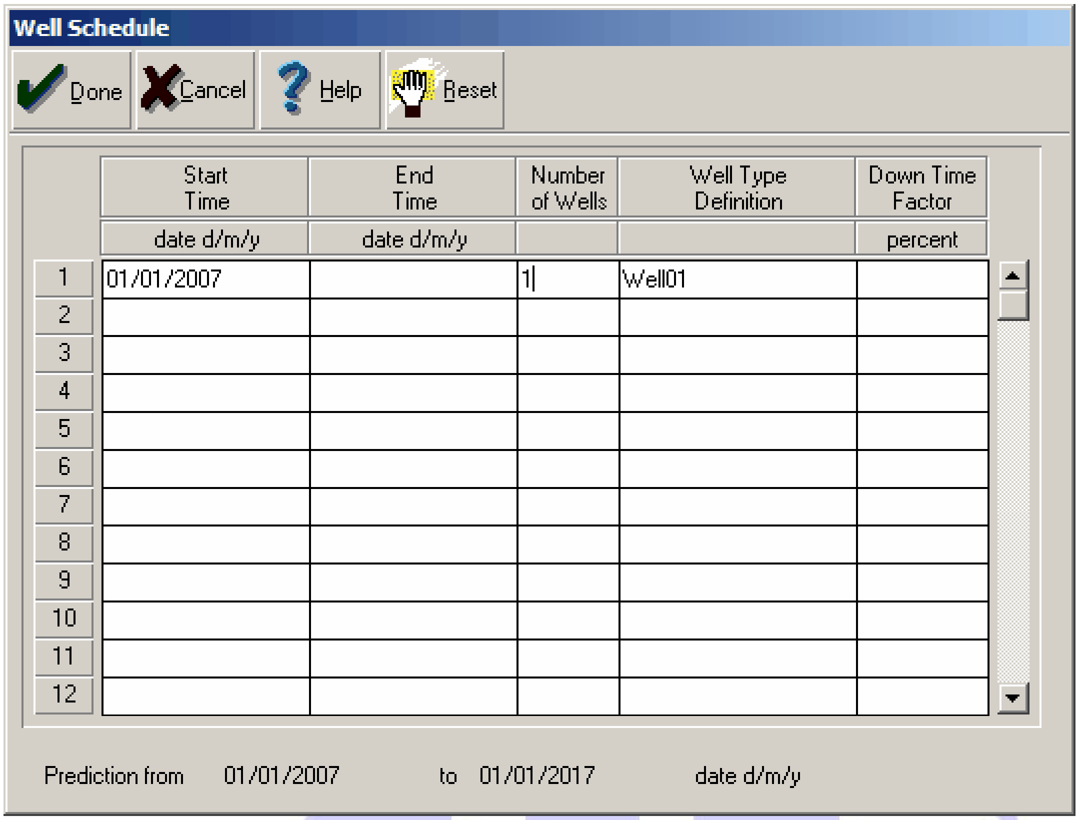
Enter the test conditions (reservoir pressure, manifold pressure, GOR, Water Cut, etc.) and click the **Calc** button. The program displays the solution points for each set of test conditions entered.

To suppress an entry, the fields in the necessary row can be blanked out.

A new record can be added to the end of the list and MBAL will automatically sort them.

2.4.6.9 The Fixed Well Schedule

This dialogue box describes the well schedule. It uses the well definitions previously entered to define the drilling program of future wells.



	Start Time	End Time	Number of Wells	Well Type Definition	Down Time Factor
	date d/m/y	date d/m/y			percent
1	01/01/2007		1	Well01	
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					

Prediction from 01/01/2007 to 01/01/2017 date d/m/y

Input Fields

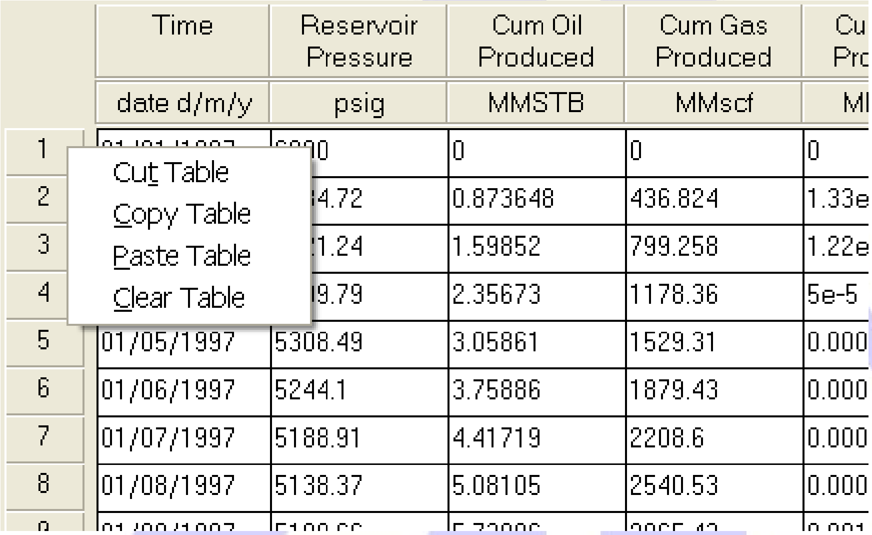
Start Time	Indicates when this well or wells will be started
End Time	Indicates when this well or wells will be shut-in. Leave blank if not to be shut-in
Number of Wells	Indicates the number of wells involved
Well Type	Indicates the well type definition involved (one of the well definitions created in the 'Well Type Definition' dialogue box)
Down-time Factor	This is a constant defining the relationship between the well average and instantaneous rates. The average rate is used to calculate the cumulative production of the well. The instantaneous rate is used to calculate well head and bottom hole flowing pressures. If 10% is entered then Qavg = Qins * (1 - 0.1). This constant can be used to take into account recurrent production shut-down for maintenance or bad weather

To remove an entry permanently, simply blank out all the fields in the corresponding row. To add or insert a new record, just enter the record at the end of the list that was already created. The program automatically sorts the entries in ascending time/data order.
Records can be switched off or on temporarily by clicking the buttons to the left of the first column entry fields. When a record is switched off, it is not taken into account in the prediction

calculations. This facility enables different simulations to be run without physically deleting the information.

- Make sure the first enabled record start time is less than or equal to the '**Start of Prediction**' time entered in the 'Reporting Schedule' dialogue box. The prediction calculation will stop if the '**End of Prediction**' is set to '**Automatic**' and there is no flowing well

- Pointing the mouse to number of any row and using the right click of the mouse will allow to access the editing options. Data can be exported/imported to the clipboard



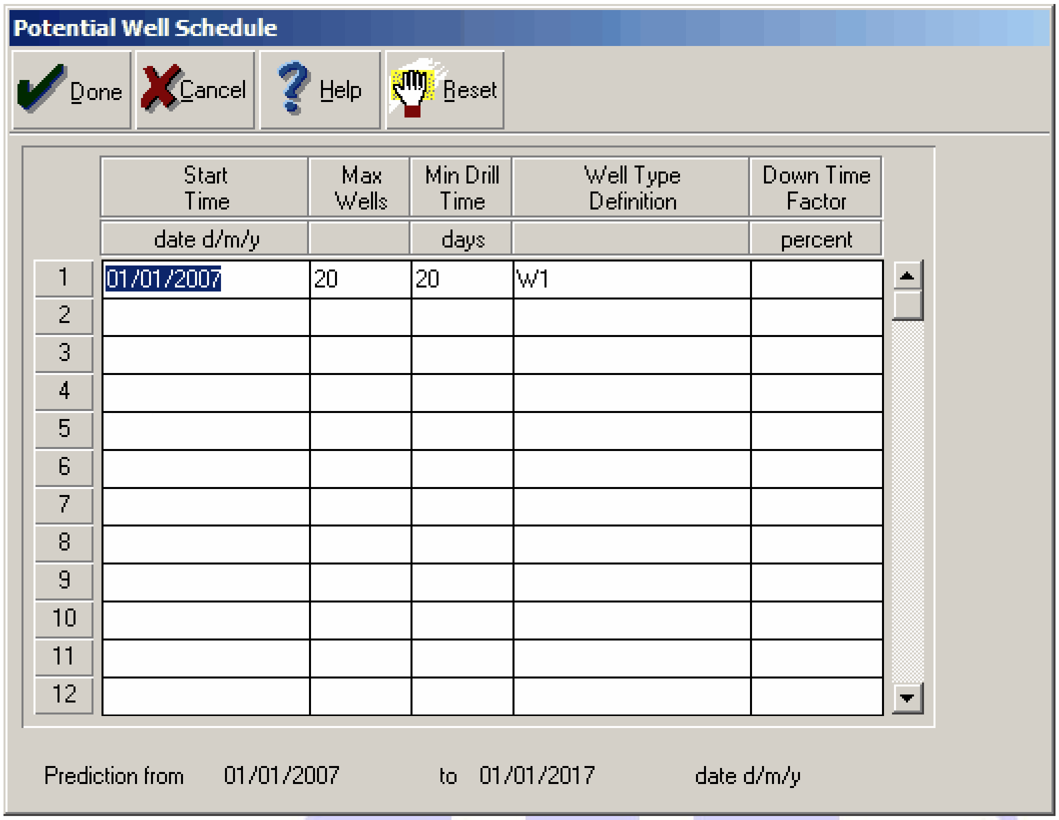
	Time	Reservoir Pressure	Cum Oil Produced	Cum Gas Produced	Cu Pro
	date d/m/y	psig	MMSTB	MMscf	MI
1	01/01/1997	[illegible]0	0	0	0
2	[illegible]	4.72	0.873648	436.824	1.33e
3	[illegible]	1.24	1.59852	799.258	1.22e
4	[illegible]	9.79	2.35673	1178.36	5e-5
5	01/05/1997	5308.49	3.05861	1529.31	0.000
6	01/06/1997	5244.1	3.75886	1879.43	0.000
7	01/07/1997	5188.91	4.41719	2208.6	0.000
8	01/08/1997	5138.37	5.08105	2540.53	0.000

Command Buttons

Reset	Click to delete all the data in the table

2.4.6.10Potential Well Schedule

This particular screen will only become active once the "Calculate Number of Wells to achieve target schedule" option is selected from the 'Options' menu. The purpose is to define the available well types for the program to choose from when calculating how many wells are needed to achieve the targets. The entry fields are shown in the screenshot below:



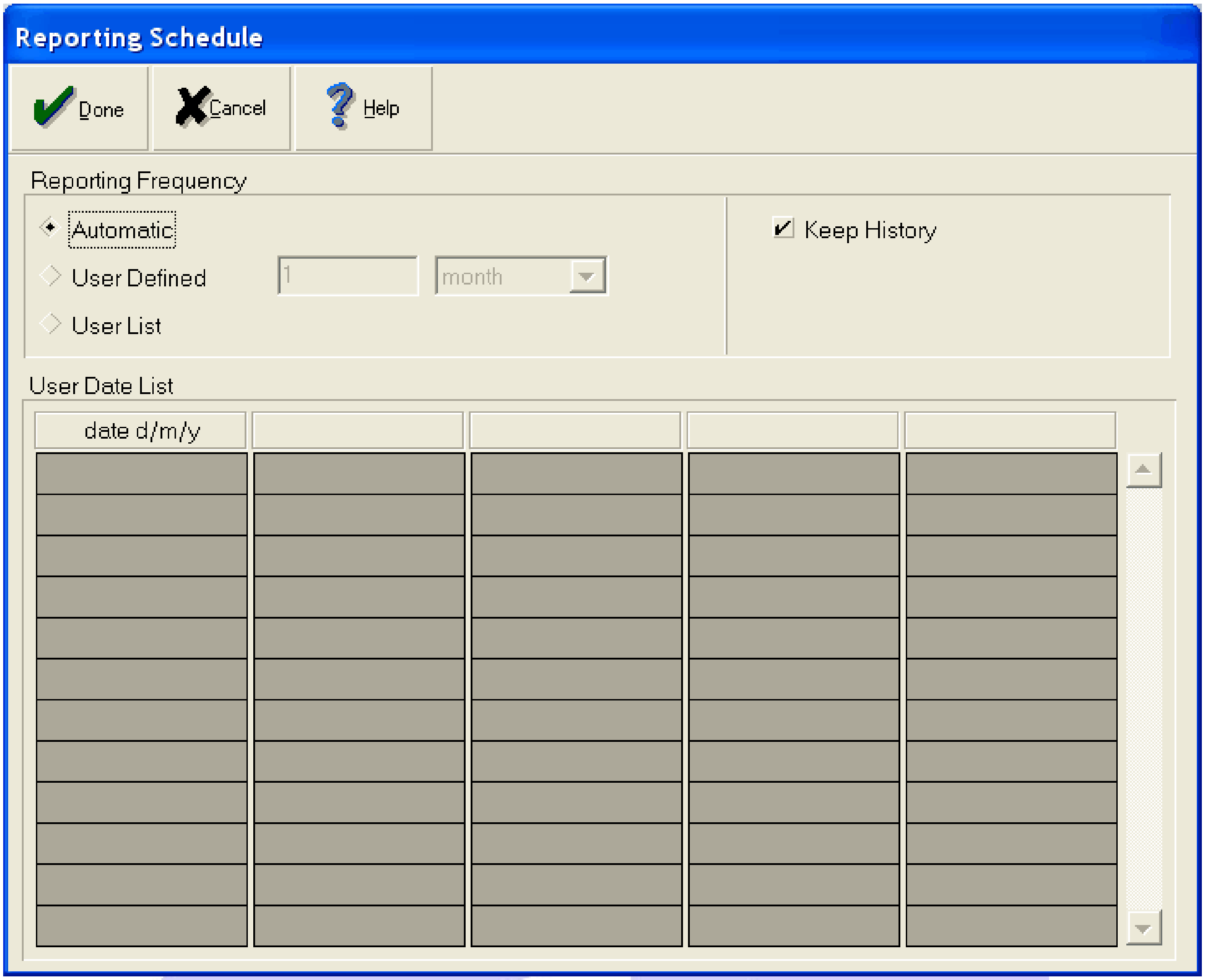
	Start Time	Max Wells	Min Drill Time	Well Type Definition	Down Time Factor
	date d/m/y		days		percent
1	01/01/2007	20	20	W1	
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					

Prediction from 01/01/2007 to 01/01/2017 date d/m/y

The 'Start Time' refers to the time from which the particular well type is available for the program to begin using. The maximum number of wells will be the maximum that the program will be allowed to choose in meeting the target. If all wells have been used and the target is not met, then normal decline will occur. The drill time will reflect on how soon the well will be brought on-line to meet the target.

2.4.6.11The Reporting Schedule

The reporting schedule defines the type of prediction to be performed, the start and end of prediction and the reporting frequency.



● Automatic
○ User Defined 1 month
○ User List

☑ Keep History

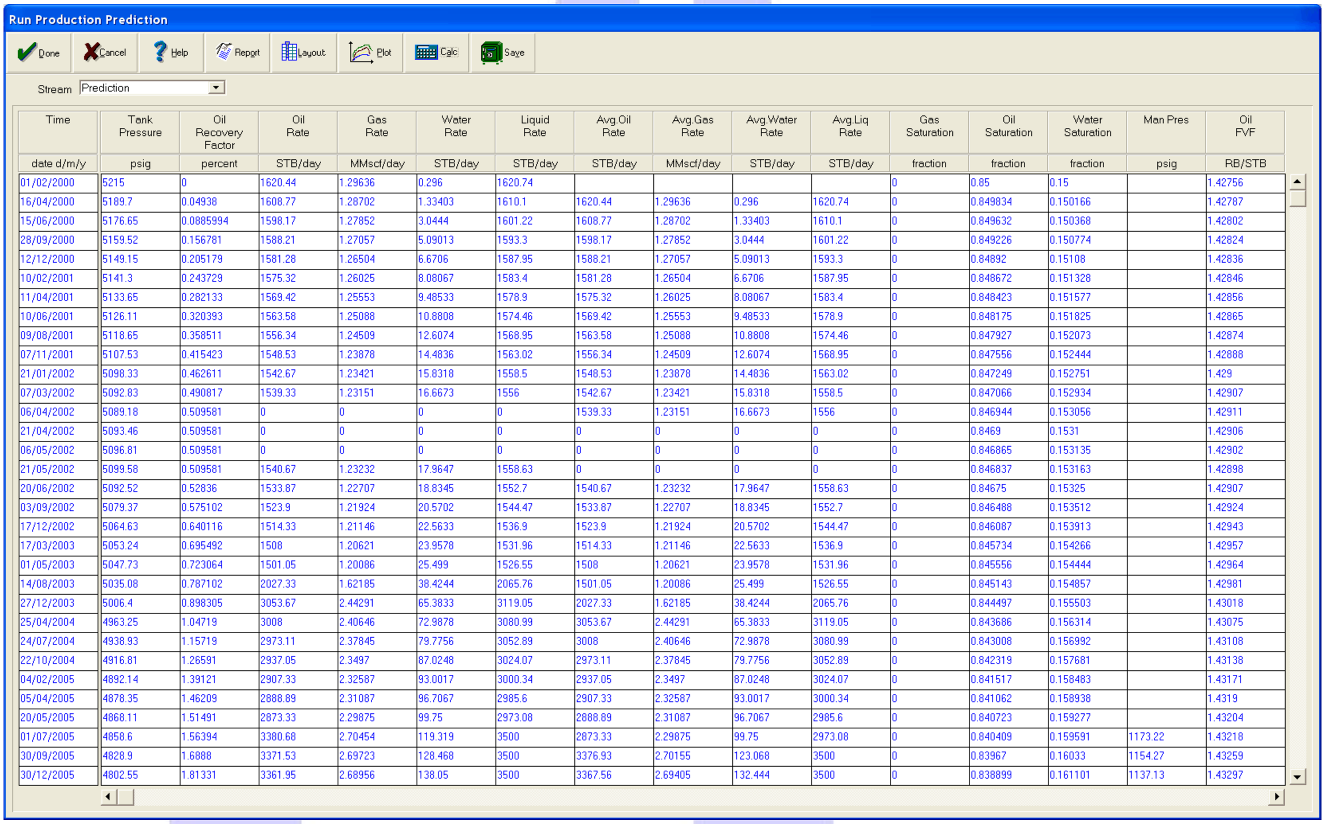
Input Fields

Reporting Frequency	This parameter defines when the prediction result is displayed	
	Automatic	The programme displays a calculation every 90 days
	User List	A list of dates can be set in the table provided. Any r can be entered and in any order - **MBAL** will sort the correct order
	User Defined	The user can defined any date increment in days, we years in the adjacent fields
Keep History	This button is only displayed for a prediction setup where the first part is actually running in history simulation mode before changing to prediction mode. If this option is selected then the calculations during the history simulation will be displayed in the results	

.

2.4.6.12Running a Prediction

A prediction can only be run after all of the necessary data has been input. To run a prediction, select **Production Prediction|Run Prediction**. The following dialogue box will then be displayed:



Stream: Prediction

Time	Tank Pressure	Oil Recovery Factor	Oil Rate	Gas Rate	Water Rate	Liquid Rate	Avg.Oil Rate	Avg.Gas Rate	Avg.Water Rate	Avg.Liq Rate	Gas Saturation	Oil Saturation	Water Saturation	Man Pres	Oil FVF
date d/m/y	psig	percent	STB/day	MMscf/day	STB/day	STB/day	STB/day	MMscf/day	STB/day	STB/day	fraction	fraction	fraction	psig	RB/STB
01/02/2000	5215	0	1620.44	1.29636	0.296	1620.74					0	0.85	0.15		1.42756
16/04/2000	5189.7	0.04938	1608.77	1.28702	1.33403	1610.1	1620.44	1.29636	0.296	1620.74	0	0.849834	0.150166		1.42787
15/06/2000	5176.65	0.0885994	1598.17	1.27852	3.0444	1601.22	1608.77	1.28702	1.33403	1610.1	0	0.849632	0.150368		1.42802
28/09/2000	5159.52	0.156781	1588.21	1.27057	5.09013	1593.3	1598.17	1.27852	3.0444	1601.22	0	0.849226	0.150774		1.42824
12/12/2000	5149.15	0.205179	1581.28	1.26504	6.6706	1587.95	1588.21	1.27057	5.09013	1593.3	0	0.84892	0.15108		1.42836
10/02/2001	5141.3	0.243729	1575.32	1.26025	8.08067	1583.4	1581.28	1.26504	6.6706	1587.95	0	0.848672	0.151328		1.42846
11/04/2001	5133.65	0.282133	1569.42	1.25553	9.48533	1578.9	1575.32	1.26025	8.08067	1583.4	0	0.848423	0.151577		1.42856
10/06/2001	5126.11	0.320393	1563.58	1.25088	10.8808	1574.46	1569.42	1.25553	9.48533	1578.9	0	0.848175	0.151825		1.42865
09/08/2001	5118.65	0.358511	1556.34	1.24509	12.6074	1568.95	1563.58	1.25088	10.8808	1574.46	0	0.847927	0.152073		1.42874
07/11/2001	5107.53	0.415423	1548.53	1.23878	14.4836	1563.02	1556.34	1.24509	12.6074	1568.95	0	0.847556	0.152444		1.42888
21/01/2002	5098.33	0.462611	1542.67	1.23421	15.8318	1558.5	1548.53	1.23878	14.4836	1563.02	0	0.847249	0.152751		1.429
07/03/2002	5092.83	0.490817	1539.33	1.23151	16.6673	1556	1542.67	1.23421	15.8318	1558.5	0	0.847066	0.152934		1.42907
06/04/2002	5089.18	0.509581	0	0	0	0	1539.33	1.23151	16.6673	1556	0	0.846944	0.153056		1.42911
21/04/2002	5093.46	0.509581	0	0	0	0	0	0	0	0	0	0.8469	0.1531		1.42906
06/05/2002	5096.81	0.509581	0	0	0	0	0	0	0	0	0	0.846865	0.153135		1.42902
21/05/2002	5099.58	0.509581	1540.67	1.23232	17.9647	1558.63	0	0	0	0	0	0.846837	0.153163		1.42898
20/06/2002	5092.52	0.52836	1533.87	1.22707	18.8345	1552.7	1540.67	1.23232	17.9647	1558.63	0	0.84675	0.15325		1.42907
03/09/2002	5079.37	0.575102	1523.9	1.21924	20.5702	1544.47	1533.87	1.22707	18.8345	1552.7	0	0.846488	0.153512		1.42924
17/12/2002	5064.63	0.640116	1514.33	1.21146	22.5633	1536.9	1523.9	1.21924	20.5702	1544.47	0	0.846087	0.153913		1.42943
17/03/2003	5053.24	0.695492	1508	1.20621	23.9578	1531.96	1514.33	1.21146	22.5633	1536.9	0	0.845734	0.154266		1.42957
01/05/2003	5047.73	0.723064	1501.05	1.20086	25.499	1526.55	1508	1.20621	23.9578	1531.96	0	0.845556	0.154444		1.42964
14/08/2003	5035.08	0.787102	2027.33	1.62185	38.4244	2065.76	1501.05	1.20086	25.499	1526.55	0	0.845143	0.154857		1.42981
27/12/2003	5006.4	0.898305	3053.67	2.44291	65.3833	3119.05	2027.33	1.62185	38.4244	2065.76	0	0.844497	0.155503		1.43018
25/04/2004	4963.25	1.04719	3008	2.40646	72.9878	3080.99	3053.67	2.44291	65.3833	3119.05	0	0.843686	0.156314		1.43075
24/07/2004	4938.93	1.15719	2973.11	2.37845	79.7756	3052.89	3008	2.40646	72.9878	3080.99	0	0.843008	0.156992		1.43108
22/10/2004	4916.81	1.26591	2937.05	2.3497	87.0248	3024.07	2973.11	2.37845	79.7756	3052.89	0	0.842319	0.157681		1.43138
04/02/2005	4892.14	1.39121	2907.33	2.32587	93.0017	3000.34	2937.05	2.3497	87.0248	3024.07	0	0.841517	0.158483		1.43171
05/04/2005	4878.35	1.46209	2888.89	2.31087	96.7067	2985.6	2907.33	2.32587	93.0017	3000.34	0	0.841062	0.158938		1.4319
20/05/2005	4868.11	1.51491	2873.33	2.29875	99.75	2973.08	2888.89	2.31087	96.7067	2985.6	0	0.840723	0.159277		1.43204
01/07/2005	4858.6	1.56394	3380.68	2.70454	119.319	3500	2873.33	2.29875	99.75	2973.08	0	0.840409	0.159591	1173.22	1.43218
30/09/2005	4828.9	1.6888	3371.53	2.69723	128.468	3500	3376.93	2.70155	123.068	3500	0	0.83967	0.16033	1154.27	1.43259
30/12/2005	4802.55	1.81331	3361.95	2.68956	138.05	3500	3367.56	2.69405	132.444	3500	0	0.838899	0.161101	1137.13	1.43297

On entering this dialogue, the results of the last prediction will be displayed, the scroll bars to the bottom and right of it allow the user to browse through the calculations.

This dialogue can also be used to display other results. Each set of results is stored in a **stream** . There are always three streams present by default:

- **Production history**
- **The last history simulation**
- **The last production prediction**

Copies of the current production prediction calculations can be made using the **Save** button. This will create a new stream.

To change the stream displayed, change the selection in the **stream** combo-box at the top left of the dialogue.

For single tank cases, each stream corresponds to the one and only tank.

For multi-tank systems, there are additional items called **sheets** which correspond to each tank or transmissibility. The results for each tank or transmissibility can therefore be displayed by selecting the relevant **sheet**.

The results displayed if the **stream** (rather than one of its sheets) is selected will display the consolidated results i.e. the cumulative results from all of the tanks.

Rates are reported in three ways in the prediction:

- Cumulative rates, i.e. the total rate produced up to the time at which the rate is reported.
- Average rate, which is the average rate over the time period from the last reported time and the time at which the average rate is reported, e.g. if reported time steps are every year then an average rate reported at 01/01/1985 is the average rate over the time period from 01/01/1984 to 01/01/1985.
- Rate: This is an instantaneous rate at the time reported.

It should be noted that if a well has a non-zero downtime value defined in the well schedule, the cumulative and average rates will include the downtime. Instantaneous rates will not however account for any downtime factor.

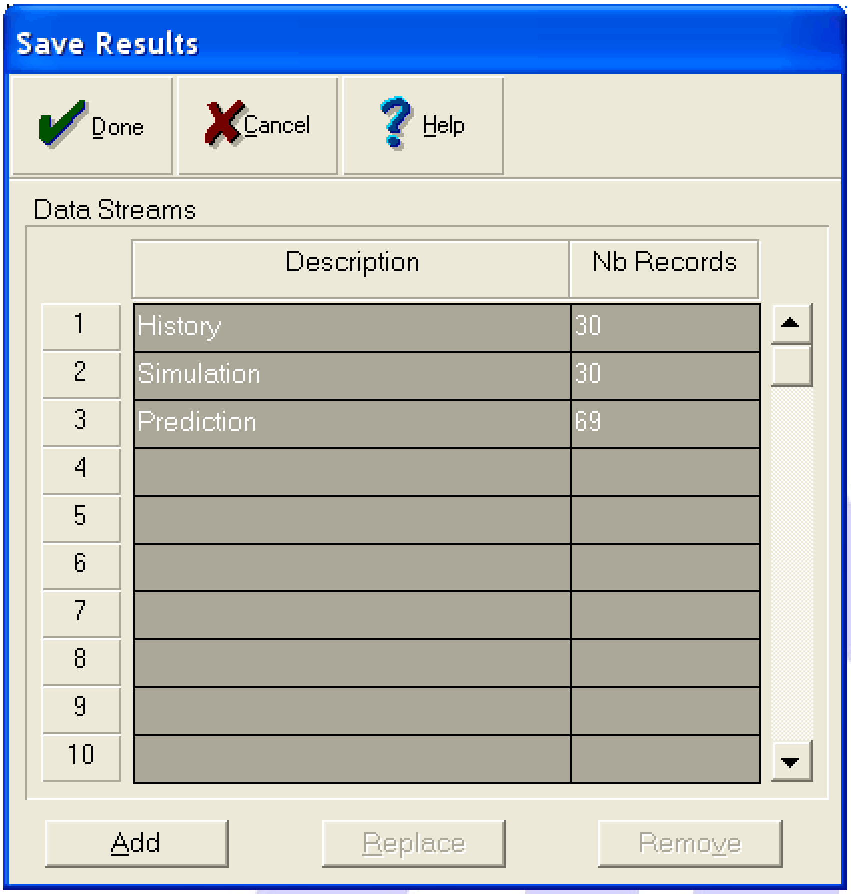
If generalised material balance is in use, separate sets of rates are reported for the oil leg manifold and the gas cap manifold. In addition there are a separate set of rates calculated from the sum of the oil leg producers and the gas cap producers.

Command Buttons

Report	Allows reporting of the currently displayed stream/sheet to a file, clipboard or printer
Layout	Allows the user to display a selection of the variables of interest. These column selections are also used by the reporting facility
Plot	Displays a plot of up to two variables from one or more streams or sheets
Calc	Click this button to start a new prediction. A small progress window with an Abort button will appear in the top right hand corner of the screen. Press the Abort button at any time to stop the calculation
Save	Use this button to save the current prediction results in a new stream. See Saving Prediction/Simulation Results for more information

2.4.6.12.1 Saving Prediction Results

At the conclusion of a prediction run, '**Save**' can be selected to store the current run in memory for comparison with other calculations. The following screen will be presented:



	Description	Nb Records
1	History	30
2	Simulation	30
3	Prediction	69
4		
5		
6		
7		
8		
9		
10		

Data Stream	Displays a list of the saved data streams. By default, three data streams will be shown: History (production history entered in the tank data) Simulation (production history simulation) Prediction (production prediction) It also displays any data streams that have been saved (see **Add** below)
Description	The program automatically provides a default description name. A new meaningful description for this prediction/simulation run by clicking on the name and editing it
Nb Records	Displays the number of calculated points for the prediction/simulation to be saved

Command Buttons

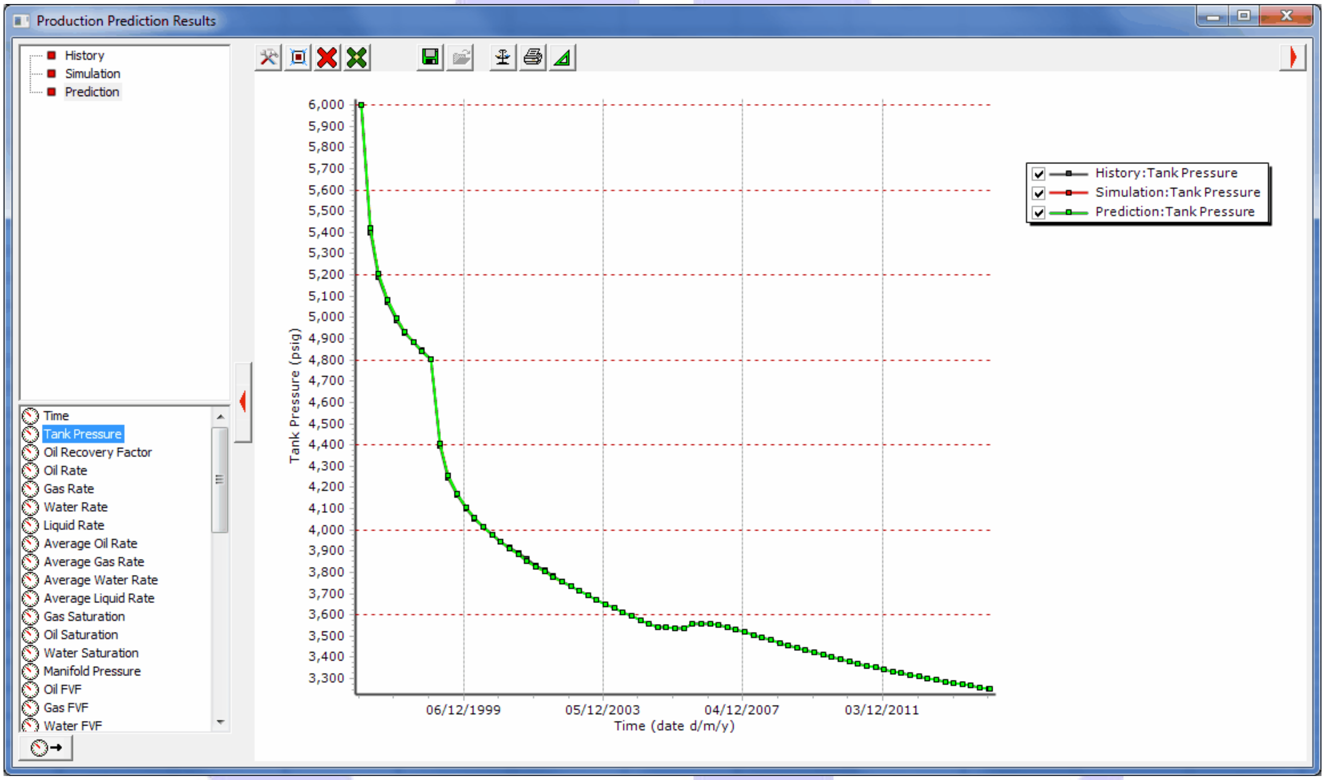
Add	Creates a new stream which is a copy of the current prediction stream. The stream is given a default name which can be altered
Replace	This can be used to replace an existing stream. Select an existing stream (not one of default ones) and click **Replace.** The selected stream will be

	replaced by a copy of the current prediction stream
Remove	Deletes the selected stream set from the list. Confirmation of the deletion will be required

Click **Done** to implement the stream changes. Click **Cancel** to exit the screen and ignore the changes.

2.4.6.12.2 Plotting a Production Prediction

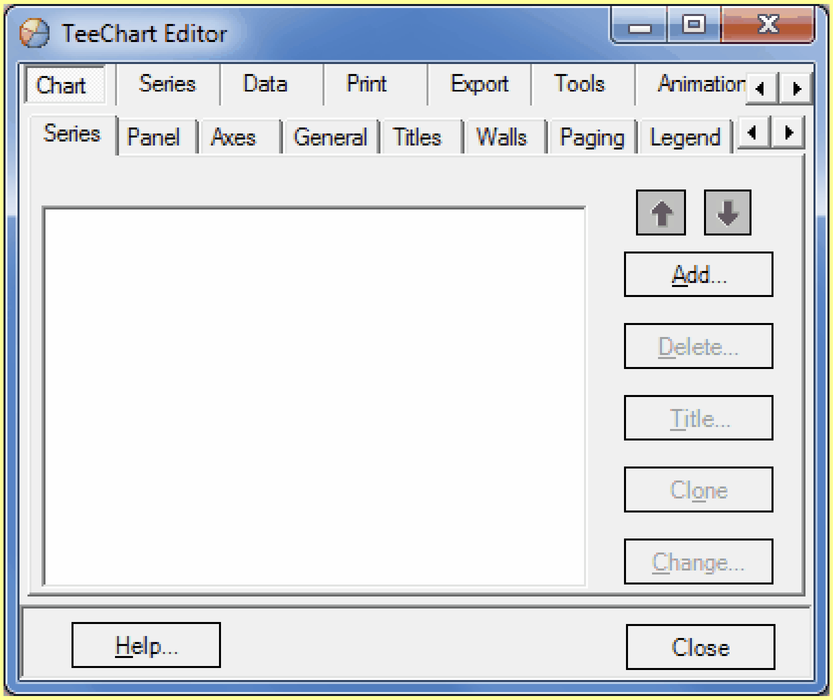
To access the prediction plotting facility, click **Plot**. A screen, such as the one below will appear:


Production Prediction Results
History
Simulation
Prediction
Time
Tank Pressure
Oil Recovery Factor
Oil Rate
Gas Rate
Water Rate
Liquid Rate
Average Oil Rate
Average Gas Rate
Average Water Rate
Average Liquid Rate
Gas Saturation
Oil Saturation
Water Saturation
Manifold Pressure
Oil FVF
Gas FVF
Water FVF
Tank Pressure (psig)
6,000
5,900
5,800
5,700
5,600
5,500
5,400
5,300
5,200
5,100
5,000
4,900
4,800
4,700
4,600
4,500
4,400
4,300
4,200
4,100
4,000
3,900
3,800
3,700
3,600
3,500
3,400
3,300
06/12/1999
05/12/2003
04/12/2007
03/12/2011
Time (date d/m/y)
History:Tank Pressure
Simulation:Tank Pressure
Prediction:Tank Pressure

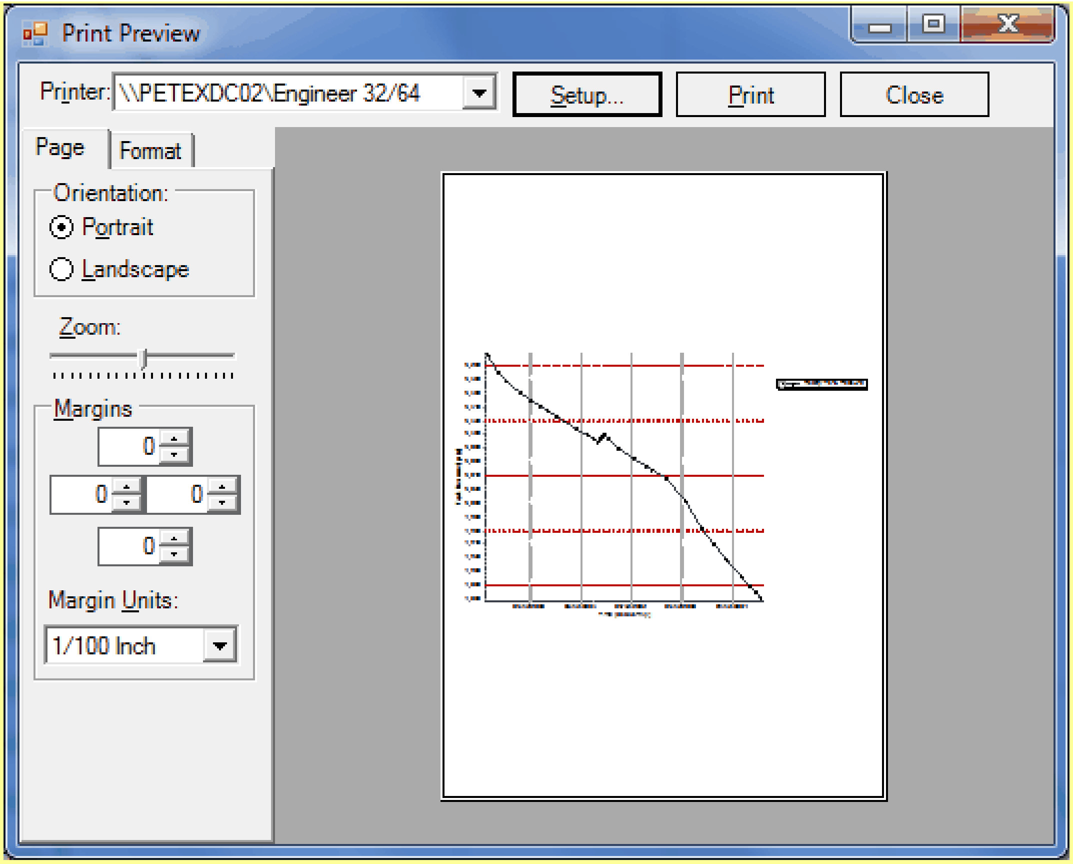
The upper left hand section can be used to retrieve various history or simulated results (including saved results) for plotting. The variables to be plotted can be selected from the lower left hand section. Note that to save a result stream, this has to be done from the calculations results interface.

A useful feature to plot multiple variables for different groups of results is by using the button. When a set of results is selected from above left section and a variable is selected from the lower left section, clicking on this button will allow to plot the same variable for the sets/ groups of results.

To change a plot display, use any of the following menu options on the plot menu bar.

<table>
<tr><td>🛠</td><td>Tee-chart editor for new Tee chart plotting feature in MBAL. The editor can be used to edit the plot display including axis, legend, data set, scales, colours e.t.c.

TeeChart Editor
Chart
Series
Data
Print
Export
Tools
Animation
Series
Panel
Axes
General
Titles
Walls
Paging
Legend
Add...
Delete...
Title...
Clone
Change...
Help...
Close

</td></tr>
<tr><td>⊡</td><td>Cancels any zoom and redraws the original plot</td></tr>
<tr><td>❌</td><td>Removes a single series from the plot through a selection interface</td></tr>
<tr><td>✖</td><td>Removes multiple series from the plot through a selection screen</td></tr>
<tr><td>💾</td><td>Use this option to save a plotting configuration which can be recalled for use later.</td></tr>
<tr><td>📂</td><td>Use this option to retrieve a saved plotting configuration</td></tr>
<tr><td>⚖</td><td>Quick access option to edit scales, legend and labels</td></tr>
<tr><td>🖨</td><td>Use to print a hardcopy of the plot(s). Selecting this option brings up the interface below where the various printers configured to the computer can be selected from. Other options include being able to select an orientation or setup paper size e.t.c.</td></tr>
</table>

	 Print Preview Setup... Print Close Page Format Zoom: Margins Printer: \\PETEXDC02\Engineer 32/64 Orientation: ● Portrait ○ Landscape Margins: 0, 0, 0, 0 Margin Units: 1/100 Inch
◢	Quick access option to edit line widths and symbol sizes

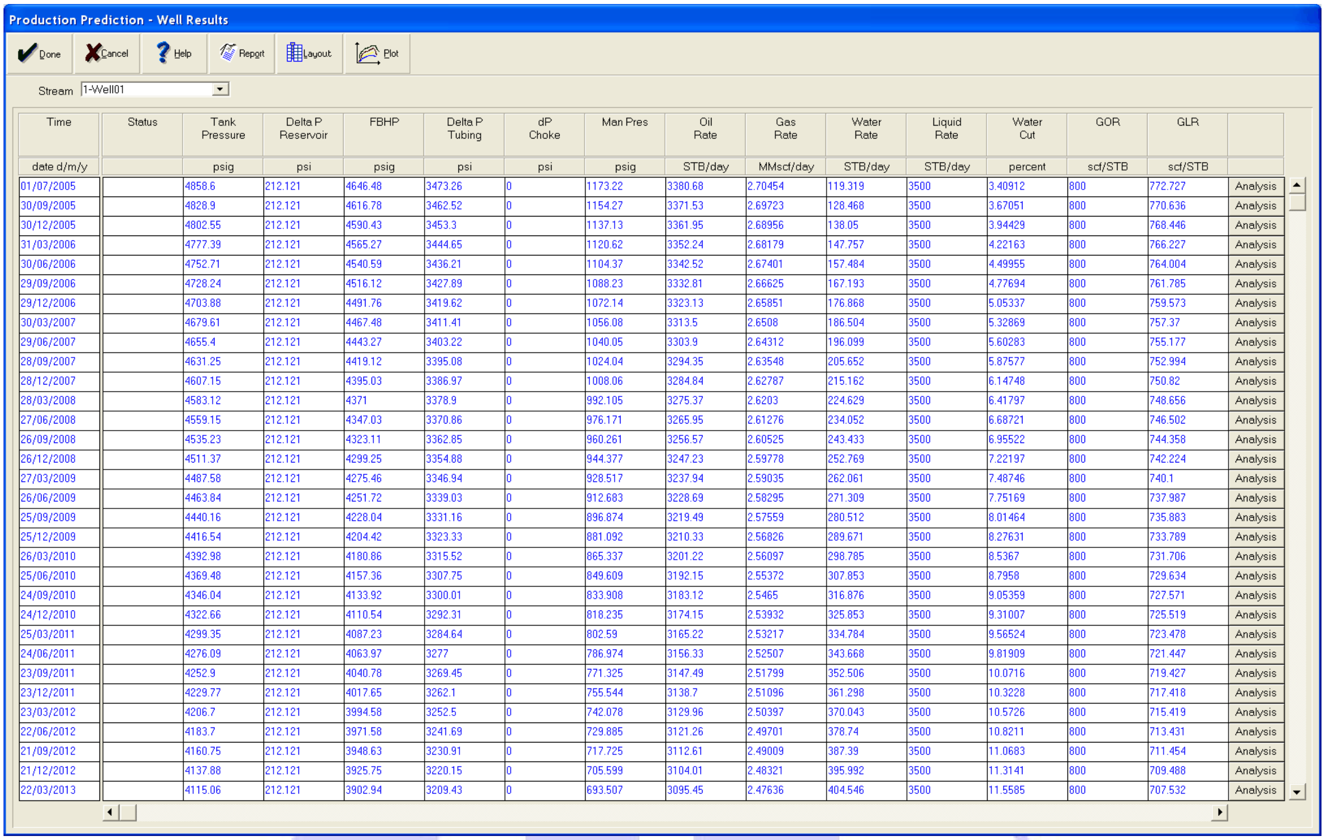
2.4.6.13 Displaying the Tank Results

To display the tank results, choose **Production Prediction|Tank Results**.

This dialogue is exactly the same as the 'Run Prediction' dialogues described above except that the 'Calc' and 'Save' buttons are not available.

2.4.6.14 Displaying the Well Results

To display the results for each well on the last prediction run, choose **Production Prediction|Well Results**. The following dialogue box will then be displayed:



Production Prediction - Well Results

Stream 1-Well01

Time	Status	Tank Pressure	Delta P Reservoir	FBHP	Delta P Tubing	dP Choke	Man Pres	Oil Rate	Gas Rate	Water Rate	Liquid Rate	Water Cut	GOR	GLR	
date d/m/y		psig	psi	psig	psi	psi	psig	STB/day	MMscf/day	STB/day	STB/day	percent	scf/STB	scf/STB	
01/07/2005		4858.6	212.121	4646.48	3473.26	0	1173.22	3380.68	2.70454	119.319	3500	3.40912	800	772.727	Analysis
30/09/2005		4828.9	212.121	4616.78	3462.52	0	1154.27	3371.53	2.69723	128.468	3500	3.67051	800	770.636	Analysis
30/12/2005		4802.55	212.121	4590.43	3453.3	0	1137.13	3361.95	2.68956	138.05	3500	3.94429	800	768.446	Analysis
31/03/2006		4777.39	212.121	4565.27	3444.65	0	1120.62	3352.24	2.68179	147.757	3500	4.22163	800	766.227	Analysis
30/06/2006		4752.71	212.121	4540.59	3436.21	0	1104.37	3342.52	2.67401	157.484	3500	4.49955	800	764.004	Analysis
29/09/2006		4728.24	212.121	4516.12	3427.89	0	1088.23	3332.81	2.66625	167.193	3500	4.77694	800	761.785	Analysis
29/12/2006		4703.88	212.121	4491.76	3419.62	0	1072.14	3323.13	2.65851	176.868	3500	5.05337	800	759.573	Analysis
30/03/2007		4679.61	212.121	4467.48	3411.41	0	1056.08	3313.5	2.6508	186.504	3500	5.32869	800	757.37	Analysis
29/06/2007		4655.4	212.121	4443.27	3403.22	0	1040.05	3303.9	2.64312	196.099	3500	5.60283	800	755.177	Analysis
28/09/2007		4631.25	212.121	4419.12	3395.08	0	1024.04	3294.35	2.63548	205.652	3500	5.87577	800	752.994	Analysis
28/12/2007		4607.15	212.121	4395.03	3386.97	0	1008.06	3284.84	2.62787	215.162	3500	6.14748	800	750.82	Analysis
28/03/2008		4583.12	212.121	4371	3378.9	0	992.105	3275.37	2.6203	224.629	3500	6.41797	800	748.656	Analysis
27/06/2008		4559.15	212.121	4347.03	3370.86	0	976.171	3265.95	2.61276	234.052	3500	6.68721	800	746.502	Analysis
26/09/2008		4535.23	212.121	4323.11	3362.85	0	960.261	3256.57	2.60525	243.433	3500	6.95522	800	744.358	Analysis
26/12/2008		4511.37	212.121	4299.25	3354.88	0	944.377	3247.23	2.59778	252.769	3500	7.22197	800	742.224	Analysis
27/03/2009		4487.58	212.121	4275.46	3346.94	0	928.517	3237.94	2.59035	262.061	3500	7.48746	800	740.1	Analysis
26/06/2009		4463.84	212.121	4251.72	3339.03	0	912.683	3228.69	2.58295	271.309	3500	7.75169	800	737.987	Analysis
25/09/2009		4440.16	212.121	4228.04	3331.16	0	896.874	3219.49	2.57559	280.512	3500	8.01464	800	735.883	Analysis
25/12/2009		4416.54	212.121	4204.42	3323.33	0	881.092	3210.33	2.56826	289.671	3500	8.27631	800	733.789	Analysis
26/03/2010		4392.98	212.121	4180.86	3315.52	0	865.337	3201.22	2.56097	298.785	3500	8.5367	800	731.706	Analysis
25/06/2010		4369.48	212.121	4157.36	3307.75	0	849.609	3192.15	2.55372	307.853	3500	8.7958	800	729.634	Analysis
24/09/2010		4346.04	212.121	4133.92	3300.01	0	833.908	3183.12	2.5465	316.876	3500	9.05359	800	727.571	Analysis
24/12/2010		4322.66	212.121	4110.54	3292.31	0	818.235	3174.15	2.53932	325.853	3500	9.31007	800	725.519	Analysis
25/03/2011		4299.35	212.121	4087.23	3284.64	0	802.59	3165.22	2.53217	334.784	3500	9.56524	800	723.478	Analysis
24/06/2011		4276.09	212.121	4063.97	3277	0	786.974	3156.33	2.52507	343.668	3500	9.81909	800	721.447	Analysis
23/09/2011		4252.9	212.121	4040.78	3269.45	0	771.325	3147.49	2.51799	352.506	3500	10.0716	800	719.427	Analysis
23/12/2011		4229.77	212.121	4017.65	3262.1	0	755.544	3138.7	2.51096	361.298	3500	10.3228	800	717.418	Analysis
23/03/2012		4206.7	212.121	3994.58	3252.5	0	742.078	3129.96	2.50397	370.043	3500	10.5726	800	715.419	Analysis
22/06/2012		4183.7	212.121	3971.58	3241.69	0	729.885	3121.26	2.49701	378.74	3500	10.8211	800	713.431	Analysis
21/09/2012		4160.75	212.121	3948.63	3230.91	0	717.725	3112.61	2.49009	387.39	3500	11.0683	800	711.454	Analysis
21/12/2012		4137.88	212.121	3925.75	3220.15	0	705.599	3104.01	2.48321	395.992	3500	11.3141	800	709.488	Analysis
22/03/2013		4115.06	212.121	3902.94	3209.43	0	693.507	3095.45	2.47636	404.546	3500	11.5585	800	707.532	Analysis

The results for the desired well can be selected from the **Stream** combo-box.

If a well has more than one layer (i.e. connection to multiple tanks), then the results for each layer will be shown as separate streams.

The **Analysis** button can be used to view the well performance for the selected row in the well results.

All of the relevant data from the well results required for the 'Well Performance Test' can be extracted to display a dialogue which allows calculation and plotting of the IPR/VLP and operating point.

This is the same dialogue which can be viewed in the 'well definition dialogue' – see section 8.5.6 above. If compositional tracking was also selected, this button could also be used to view the details of the composition of the well for the selected row.

In the **Status** column, the program shows any special conditions for that well. These may be:

Abd CGR	Abandonment on CGR constraint
Abd Gas	Abandonment on Gas saturation constraint
Abd GOR	Abandonment on GOR constraint

Abd Wat	Abandonment on Water saturation constraint
Abd WC	Abandonment on WC constraint
Abd WGR	Abandonment on WGR constraint
Abd WOR	Abandonment on WOR constraint
End Date	Automatic Well shut-down according to well schedule
Gas Brk	Gas breakthrough
Gas Levl	Abandonment on Gas Contact depth
Man Gmax	Rate reduced because of Gas Rate constraint
Man Pmax	Rate reduced because of Manifold Maximum pressure
Man Pmin	Abandonment because of Manifold Minimum pressure
Man Qmax	Rate reduced because of Manifold Maximum rate
Man Qmin	Abandonment because of Manifold Minimum rate
Max DwDn	Rate reduced because of Maximum Drawdown on the formation
Max FBHP	Rate reduced because of Maximum Flowing Bottom Hole Pressure
Max Rate	Rate reduced because of Maximum Well Rate
Man Wmax	Rate reduced because of Water Rate constraint
Min FBHP	Abandonment on Minimum Flowing Bottom Hole Pressure
Min Rate	Abandonment on Minimum Well Rate
Neg TPC	The IPR intersects the TPC on the negative slope of the TPC
No OptGl	Optimum GLR could not be provided a Gas Lifted Well because of a constraint on the maximum gas lift gas available
No Solut	No IPR / TPC intersection
Out TPC	Program working outside of the TPC's generated range
Wat Brk	Water breakthrough
Wat Levl	Abandonment on Water Contact depth

2.4.6.15Production Prediction Reports

A report of the input menu parameters can be generated, once the relevant data has been supplied. Reports can be printed to include all the information entered so far, or printed to include only specific categories of data.

To print a report select **Production Prediction | Report** or click **Report** in the relevant dialogue box. Select the categories of data to print by checking the box to the left of the entry.

The selected categories are retained in memory and re-printed each time a report is generated.

Categories between brackets, (e.g. PVT) indicate further report levels can be selected. To access these, double-click the category name.

The following levels of Input data are accessible:

General Information	See Material Balance reports for information
PVT	See PVT reports for information
Input	See Material Balance reports for information
Relative Permeabilities	Includes the Corey functions or table information entered in the 'Relative Permeabilities' dialogue box
Production and Constraints	Includes the parameters used to calculate the average gas cap gravity and water salinity, as well as the constraints for the tank. Where gas is the primary fluid, this includes the parameters describing the pressure and rate constraints on the production and injection manifold
Well Definitions	Includes the well type definitions used to define the production or well schedule driving the production prediction calculations
Well Schedule	Includes the data describing the input wells or production schedule
Tank Results	Includes the results of the last prediction calculation
Well Results	Includes the results of the last prediction calculation

See Reports for information on selecting the report output and format.

2.4.7 Coalbed Methane Overview

Coalbed Methane (CBM) is a category of unconventional gas reservoirs. However it is becoming very important due to the large amount of reserves all over the world. For example it is estimated that there is over 100 Tcf of recoverable reservoirs in USA alone.

In a conventional gas reservoir the gas is present in the pores of the rock. In a CBM reservoir there may also be gas present in the rock pores but there will also be gas adsorbed on the surface of the coal.

Note that the gas is a**D**sorbed, not a**B**sorbed. The difference is that in aDsorption the gas is a film of molecules on the surface of the rock whereas in aBsorption the gas is held within the material (e.g. CO2 in water).

Often the CBM reservoir may initially only contain water in the pore space. In this case some of the water must be produced (de-watering) to reduce the pressure and thus desorb some of the gas into the free phase in the pore space.

Coal is naturally highly fractured. Fractures (cleats) are aligned approximately horizontal and vertical. Horizontal fractures are known as face cleats and vertical fractures as butt cleats. The horizontal fractures provide much more permeability than the vertical fractures. The actual coal matrix has very low permeability and porosity so the fractures provide nearly all of the flow in the reservoir.

The main method of modeling CBM reservoirs is the **Langmuir Isotherm**. This models the amount of gas that is adsorbed in the coal. As the pressure in the reservoir decreases the amount of gas adsorbed in the coal decreases and thus how much is desorbed into the free phase. The Langmuir Isotherm defines the relationship between the pressure and the amount of gas that is adsorbed in the coal (per volume or mass). Coal bed methane can be used in material balance module as well as the tight gas module.

Material Balance	The desorbed gas is included in all the material balance calculations including all history matching methods and prediction. At any pressure the desorbed gas can be calculated and added to the free gas in the reservoir. This method is outlined in “King, Material Balance Techniques for Coal Seam and Devonian Shale Gas Reservoirs, SPE 20730”. An additional graphical plot has been added to the History Matching section. This is a variation of the P/Z plot which takes the desorbed gas into account as well as connate water expansion and any aquifer. This is called the King P/Z* plot and is also described in “King, Material Balance Techniques for Coal Seam and Devonian Shale Gas Reservoirs, SPE 20730”
Tight Gas	All methods in the tight gas tool have been modified to handle coalbed methane. The method used is described in “Bumb, McKee, Gas-Well Testing in the Presence of Desorption for Coalbed Methane and Devonian Shale, SPE 15227”. An important input to the tight gas models is the total compressibility which includes the gas compressibility. As the pressure drops the original gas volume increases thus defining the gas compressibility. In CBM as the pressure drops the original gas volume effectively increases by the addition of desorbed gas as well as the expansion of the original gas. So if a corrected gas compressibility is used which includes the desorption term then all the equations for normal tight gas model can be used as normal. By using this corrected Cg to transform the data for the type-curve plots, the effect of the desorbed gas is removed and so it can be compared against conventional type-curves

Diffusion Model

The Langmuir Isotherm gives a relationship between adsorbed gas and pressure. So if one drops from a pressure P1 to a pressure P2 the amount of gas adsorbed decreases from Ve1 to Ve2. This means that Ve1 - Ve2 is desorbed as free gas. Strictly this description is only true if an infinite amount of time passes after the pressure drops. This is because the desorption is not instantaneous. There is a time delay because of diffusion.

In practise it can often be assumed that the desorption is instantaneous. However in some cases it is neccessary to model this diffusion effect.

Material Balance Diffusion:

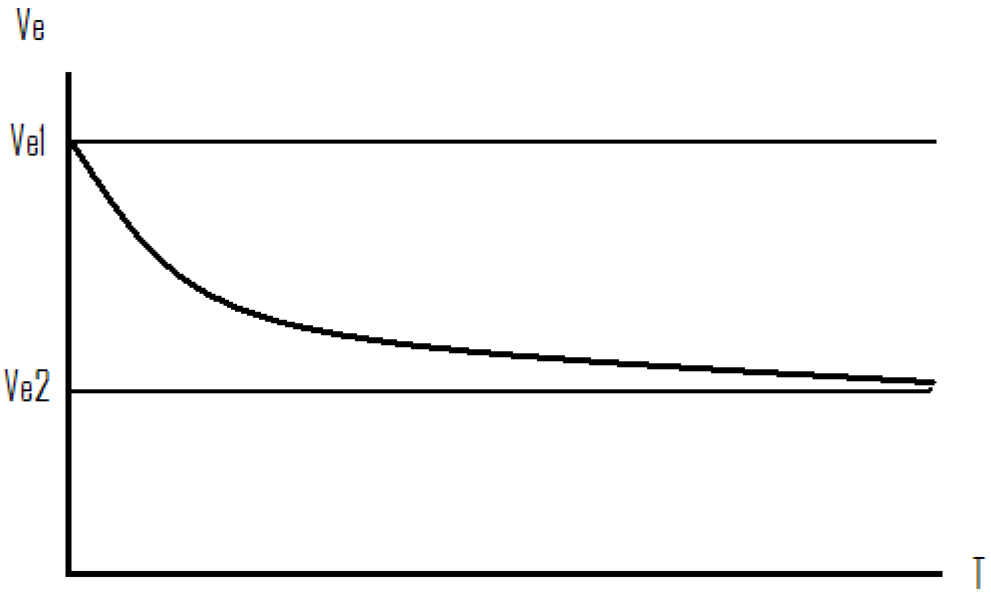
Diffusion is normally modelled by Fick's Law. However this requires the relevant distances to be known. Since material balance is a zero dimensional model (i.e. no geometry is known), we can not use it.

Instead we use a modifed form of Fick's Law proposed in “King, Material Balance Techniques for Coal Seam and Devonian Shale Gas Reservoirs, SPE 20730”. This is based on time rather than distance.

The solution to this equation is as follows where "D" is the diffusion constant. If we start at a pressure where Ve = Ve1 and drop to a pressure where Ve = Ve2 then the Ve taking into account the diffusion is:-

Ve = Ve2 + (Ve1 – Ve2)*exp(-Dt)

At small times, exp(-Dt) is nearly 1.0 so Ve will still be very close to Ve1. At large times exp(-Dt) is nearly zero so Ve is nearly Ve2. So the following behaviour will be seen.



This is only for one pressure drop. To handle a depletion in the reservoir the principal of superposition is used to add the diffusion effects from each pressure drop to the total pressure drop.

Note that in King's paper he used exp(-Dat) where "a" was the shape factor. Since this variable is only used when multiplied with "D", it was omitted. If you have known values of "D" and "a", simply multiply them together and enter them as "D".

Often a value of D will be unavailable in which case it can only be used as a match parameter.

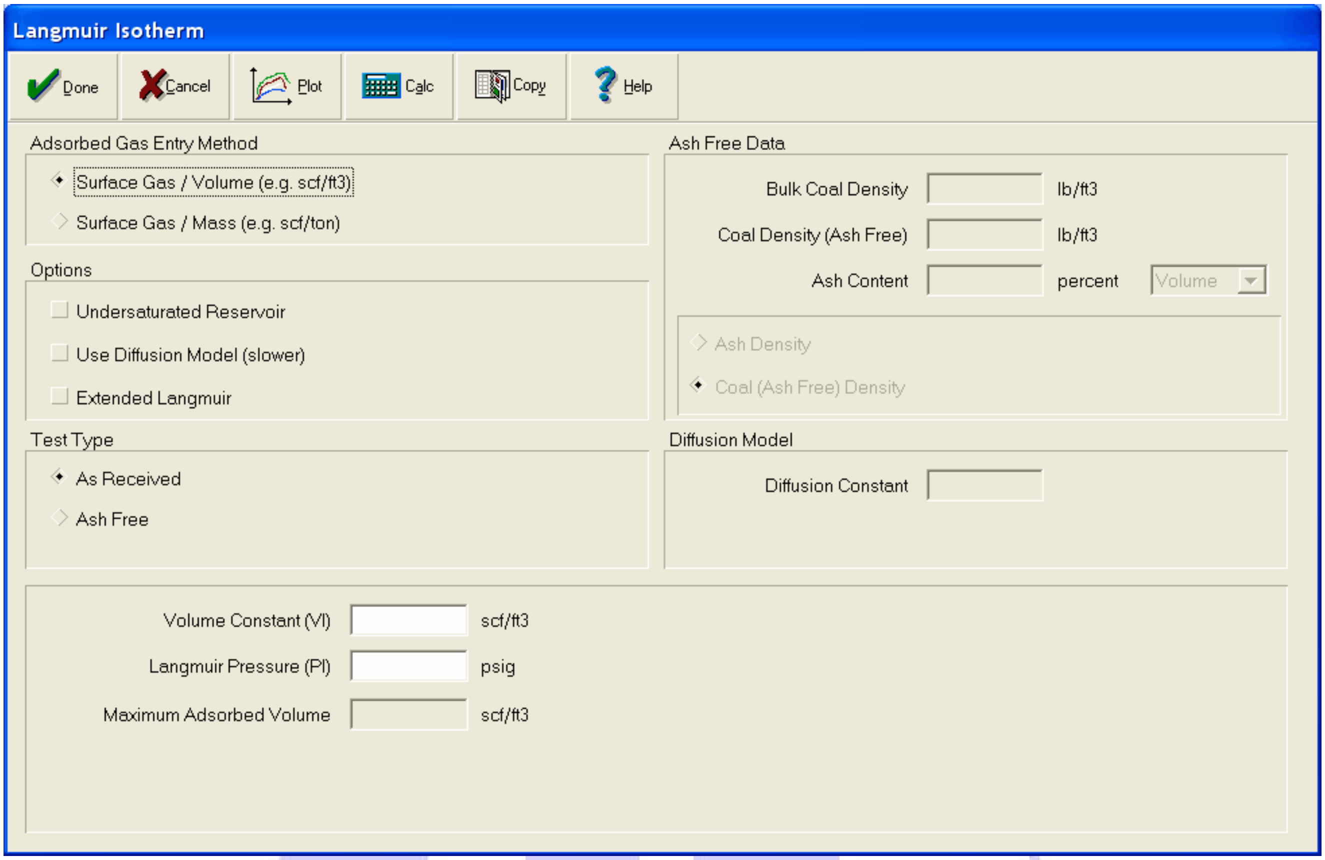
Tight Gas Diffusion:

A diffusion term is already included in the model of Bumb & McKee. The extra Cg term describing the desorption is divided by the Diffusion Constant. So a large Diffusion Constant will give a delayed effect from the desorption. A diffusion constant of 1.0 will predict instantaneous desorption.

WARNING : The diffusion constant should never be less than 1.0 as this will give a greater gas desorption than the Langmuir Isotherm predicts.

2.4.7.1 Langmuir Isotherm Editor

The Langmuir Isotherm defines the relationship between the reservoir pressure and the amount of gas adsorbed in the reservoir. It is fundamental in modeling Coalbed Methane reservoirs.



Adsorbed Gas Entry Method

● Surface Gas / Volume (e.g. scf/ft3)

○ Surface Gas / Mass (e.g. scf/ton)

Options

☐ Undersaturated Reservoir

☐ Use Diffusion Model (slower)

☐ Extended Langmuir

Test Type

● As Received

○ Ash Free

Ash Free Data

Bulk Coal Density lb/ft3

Coal Density (Ash Free) lb/ft3

Ash Content percent Volume

○ Ash Density

● Coal (Ash Free) Density

Diffusion Model

Diffusion Constant

Volume Constant (Vl) scf/ft3

Langmuir Pressure (Pl) psig

Maximum Adsorbed Volume scf/ft3

Adsorbed Gas Entry Method

Langmuir Isotherm data is sometimes reported as adsorbed gas per downhole bulk volume and sometimes per coal mass. Select which method you wish to use to enter the data.
If "Surface Gas / Volume" is selected then the bulk coal density must also be entered.

Options

Undersaturated Reservoir	Normally the Langmuir Isotherm will predict that the amount of gas adsorbed will continue to increase as the pressure increases. However in practise the coal may be undersaturated which means that there is a pressure beyond which the amount of adsorbed gas will not increase. If this is the case, select the "Undersaturated Reservoir" option. You will then be able to enter the maximum adsorbed volume
Use Diffusion Model	(slower) The Langmuir Isotherm predicts that the when the pressure drops, the amount of gas adsorbed in the coal will drop thus releasing the difference into the free gas phase. However if the pressure drop is effectively instantaneous, in practise the desorbed gas will take some time to move into the free phase. In practise this time delay can often be ignored - in this case do not select

	this option. If you wish to model this time delay then select this option to use the diffusion model. Note that for material balance, this model will make the calculations much slower
Extended Langmuir	Different gases will have different adsorption properties (e.g. CO2, CH4 etc). The normal Langmuir Isotherm is strictly only applicable for pure methane reservoirs or where the different adsorption properties are similar. If adsorption data is available for the different gases in the reservoir (in the form of extended Langmuir Isotherms) then select this option. It will then be possible to enter Langmuir Isotherm data for each gas

Test Type

Ash is present in all coal. This is the inorganic material present in the coal. Ash will not adsorb gas so if there is a large amount of ash in the coal, a sample will adsorb less gas than similar coal but with much less ash.

As Received	means that the data applies to the coal as it was taken from the reservoir and thus already accounts for any ash in the coal
Ash Free	means that the data applies to a sample of coal after the ash has been removed. This means that the adsorption properties will be higher than the actual coal

Therefore **MBAL** must reduce the adsorption to account for the ash. To allow this, the ash and density data must be entered as explained below.

Ash Free Data

Ash Content	The amount of ash in the coal. This can be entered either by volume or by mass. If entered by volume then no density data is required
Bulk Coal Density	Density of the bulk coal including any ash (this is also required if entering data as adsorbed gas per mass)
Coal Density	(Ash Free) The density of the coal with the ash removed
Ash Density	The density of the ash removed from the coal
Ash Density/Coal (Ash Free Density)	To correct the Langmuir Isotherm for Ash we need the Bulk Coal Density and either the Ash Density or the Coal (Ash Free Density). Select which of these two densities you wish to use

If the Ash Content was entered per mass the correction to the Langmuir Isotherm is as described in “Scott, Zhou, Levine, A Modified Approach to Estimating Coal and Coal Gas Resources: Example from the Sand Wash Basin, Colorado”.

Diffusion Model

Diffusion Constant	If the diffusion model was selected, enter this value to define the diffusion. See the Coalbed Methane Introduction 332 for an explanation of the diffusion model

Langmuir Isotherm Data

For normal Langmuir Isotherm the equation is:-

Ve = (VL * P)/(PL + P)
Ve is the amount of adsorbed gas (per downhole volume or mass depending on entry type).
VL - Volume Constant
PL - Langmuir Pressure

If "Undersaturated Reservoir" was selected then you must also enter the Maximum Adsorbed

Volume. This value will be the upper limit on the value of Ve calculated by the equation above.

Note that instead of PL a value called b is often provided which has the units of 1/pressure. If this is the case, PL is simply 1/b.

Extended Langmuir Isotherm Data

If the Extended Langmuir Isotherm option was selected, a Langmuir Isotherm must be entered for each gas (CH4, CO2, N2, H2S). In this case the equations are:-

$$V_{Ei} = \frac{V_{Li} b_i P y_i}{1 + \sum_j b_j P y_j}$$

i is the index of the component
VLi is the Langmuir Volume for the ith component.
bi is the equivalent of the Langmuir Pressure in units of 1/pressure for the ith component. If your data is in the form of PL then b is simply 1/PL .
y is the molar composition in the free phase of the ith component.

Instead of entering the initial free gas fractions the initial adsorbed gas fractions are entered. The initial free gas fractions are then calculated from the initial adsorbed fractions using the extended Langmuir isotherm.

It is not necessary to enter data for all components e.g. data for only CH4 and CO2 could be entered. If you do not have any N2 for example, enter Vl, b and initial adsorbed fraction = 0.0.

This method is described in more detail in Appendix B of “Clarkson, Jordan, Gierhart, Seidle, Production Data Analysis of CBM Wells” SPE 107705. However in MBAL the "y" values are solved at the same time as the pressure which is a more stable solution method than the method proposed by Clarkson et al.

Note that if this option is used, the impurities in the input PVT model is ignored.

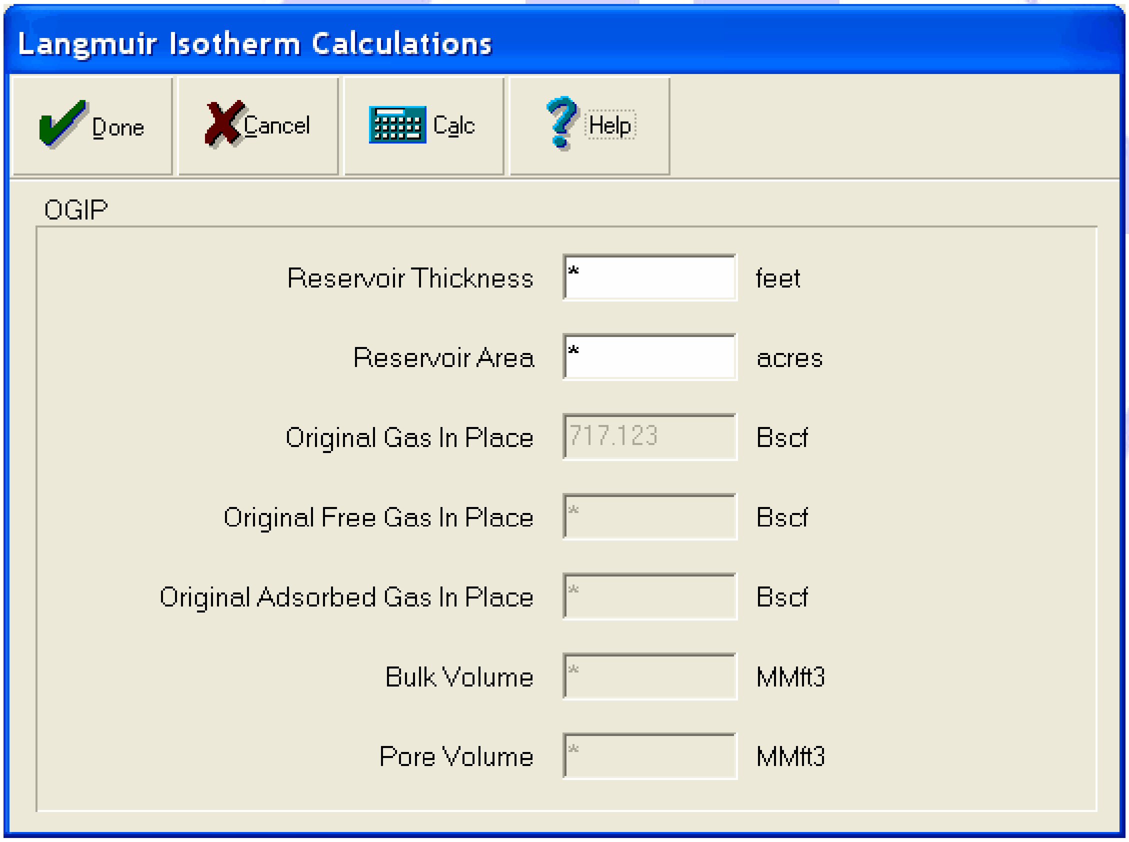
Original Data

Within the history matching section it is possible to regress on some of the parameters in the Langmuir Isotherm i.e. PL, VL and the diffusion constant. However it is important to be able to see the original value that was entered from test data. If any of these data items is changed from the original entered value the **Original Data** button will be displayed. Click this button to view and reset the original values.

Plot	display the Langmuir Isotherm
Calculate	use the Langmuir Isotherm to calculate an estimate of OGIP based on the reservoir volume
Copy	copy a Langmuir Isotherm from another tank

2.4.7.1.1 Langmuir Isothem Calculation

This dialogue is used to provide an estimate of the OGIP for a given Langmuir Isotherm.



OGIP

Reservoir Thickness * feet

Reservoir Area * acres

Original Gas In Place 717.123 Bscf

Original Free Gas In Place * Bscf

Original Adsorbed Gas In Place * Bscf

Bulk Volume * MMft3

Pore Volume * MMft3

Enter the dimensions of the reservoir, reservoir thickness and area, and then click the **Calc** button.

The Original Gas in Place is the free + adsorbed gas in the reservoir. This is the value which should be used in the tank parameters and so it will automatically be copied to the tank parameters tab.

2.4.7.1.2 Langmuir Isothem Plot

This plot displays the Langmuir Isotherm. This defines the relationship between how much gas is adsorbed in coal as pressure varies.

If "Extended Langmuir Isotherm" was selected then the isotherm for each gas component is plotted.

2.4.7.1.3 Langmuir Isothem Original

The Langmuir Isotherm data is normally provided from test data. However it is possible to use these parameters to match production history in the history matching section.

If the original entered parameters have been changed it is useful to be able to view the original entered parameters.

The "Original" data is the first values that were entered.
The "Working" data is the current values that have been matched or edited.

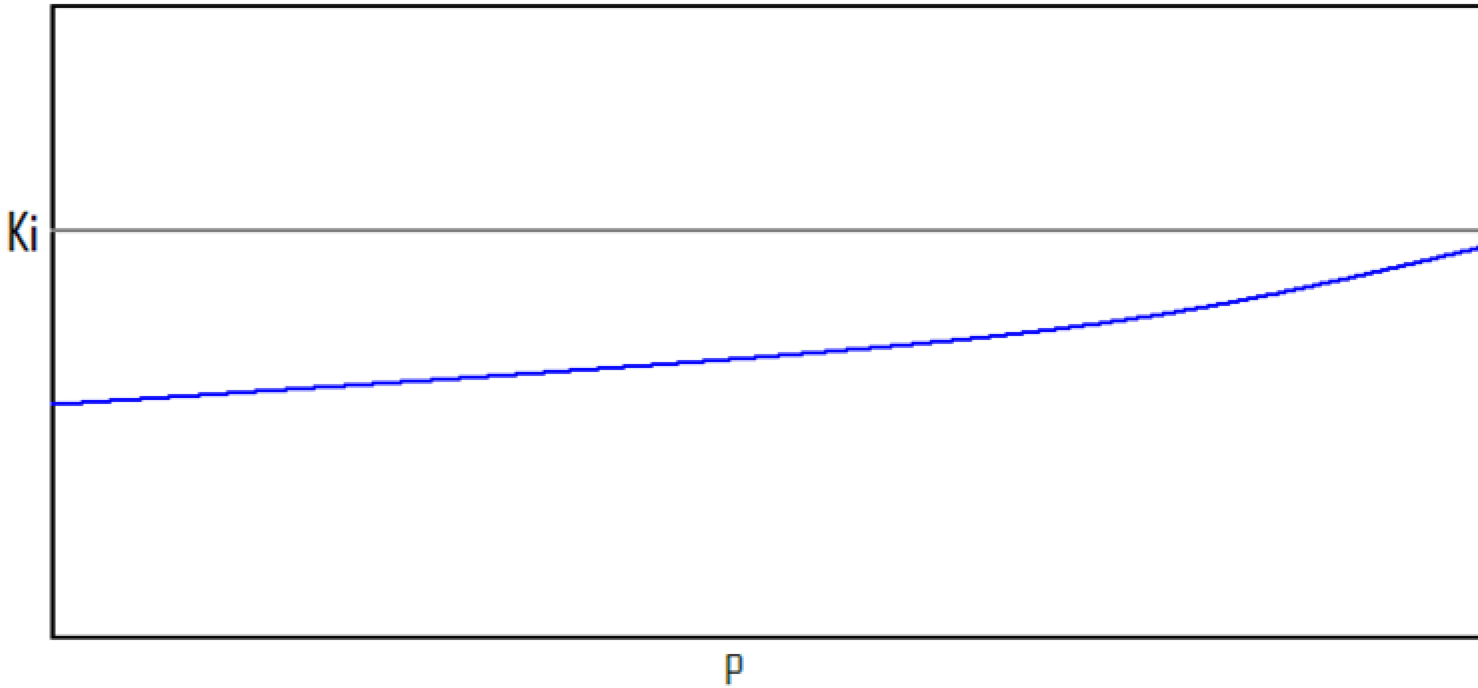
The dialog displays the original data.

Copy Original to Working	reset the current data to the original data
Copy Working to Original	reset the original data to the current data

2.4.7.2 Coal Permeability Variation Model

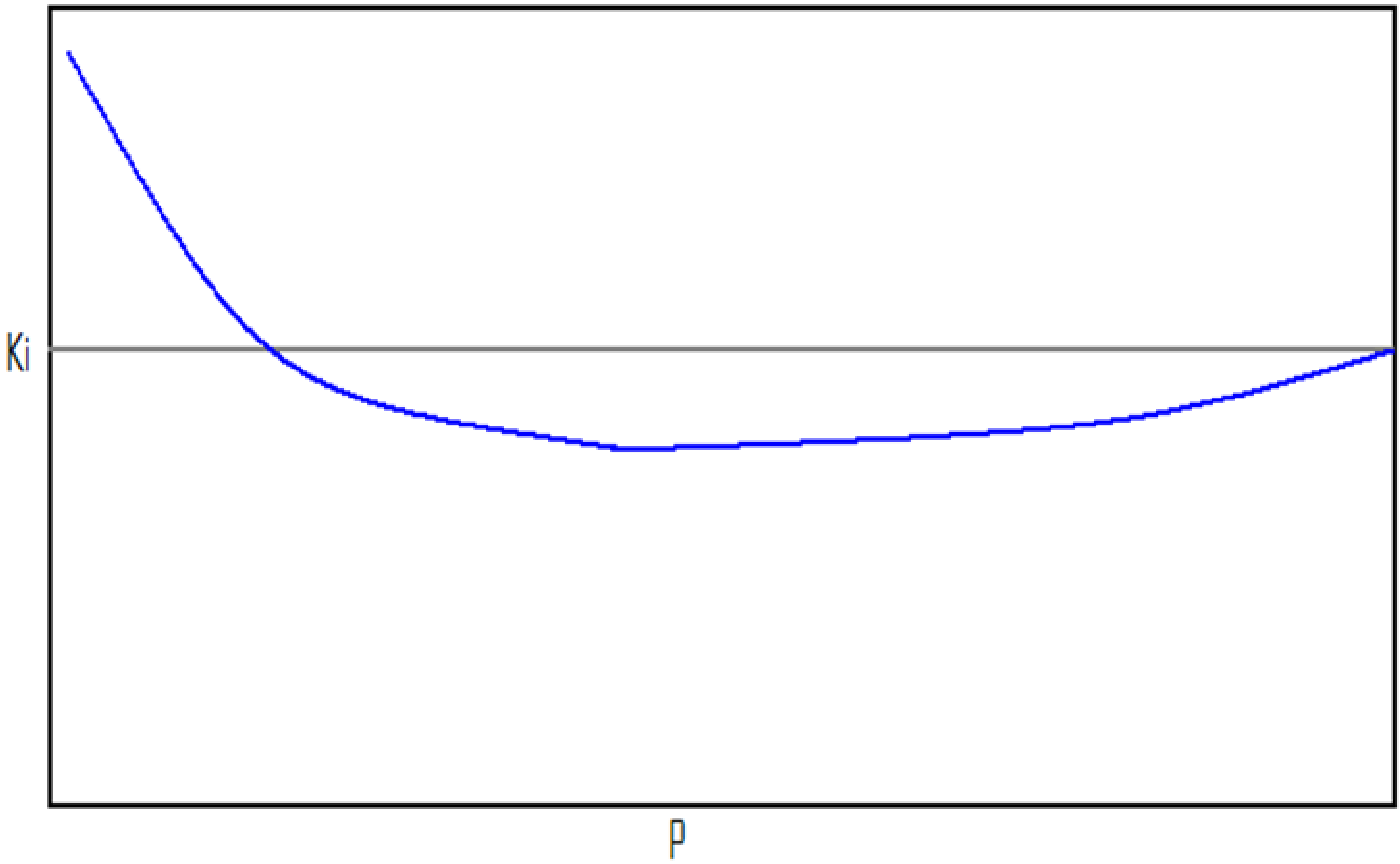
This dialogue is used to set up a model to predict permeability variation for coalbed methane reservoirs.

For conventional gas reservoirs, as the pressure decreases the permeability normally decreases. This is due to the rock grains being pressed closer together thus reducing the space through which to flow and so reducing the permeability (see below).



In coalbed methane reservoirs the behaviour is different. Coal is naturally fractured and nearly all of the permeability is provided by the fractures rather than the coal matrix.

Initially as the pressure drops the coal blocks are pressed closer together so the fractures get smaller and the permeability reduces (like a conventional gas reservoir). However as the pressure drops further a large amount of gas is desorbed which means the coal blocks shrink in size which increases the fracture widths and thus the permeability. So the pressure drop is both increasing and decreasing the permeability - it depends on which effect is the stronger as to the shape of the final permeability vs pressure curve. Often the following plot is seen where the block shrinkage only has an effect at lower pressures and hence the rebound that is often seen in the field.



A number of models have been developed to predict this permeability variation for coal:

Seidle-Huitt	model as described in “Seidle, Huiit, Experimental Measurement of Coal Matrix Shrinkage Due to Gas Desorption and Implications for Cleat Permeability Increases, SPE 30010”
Palmer-Mansoori	model as described in “Palmer, Mansoori, How Permeability Depends on Stress and Pore Pressure in Coalbeds: A New Model, SPE 36737”
Shi-Durucan	model as described in “Shi, Durucan, A Model for Changes in Coalbed Permeability During Primary and Enhanced Methane Recovery, SPE 87230”
User Entered	this allows you to directly enter the relationship between pressure and permeability ratio i.e. k(P)/k(Pi) from any other model

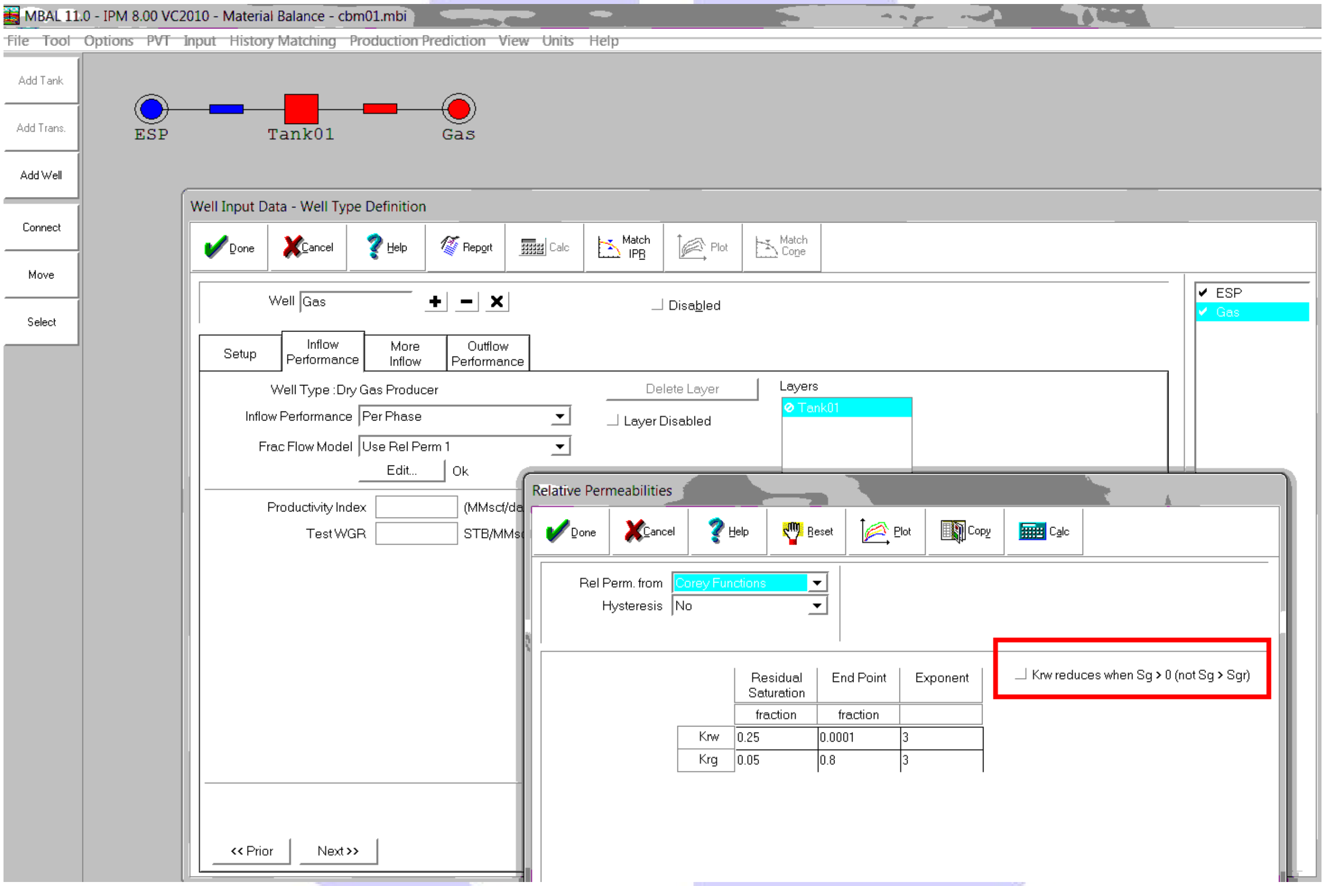
Note that this permeability variation is used to correct the IPR calculations in the Production Prediction. It will not affect the material balance calculations other than that the corrected IPR will predict a different rate and hence a different tank pressure. It will not affect the history matching.

Relative Permeability Correction (*New in IPM 8.0*)

Unlike standard gas reservoirs, a coal reservoir is usually full of water with no free gas. As the reservoir is depressurised gas will come into the free phase. However the free gas may not be produced until it reaches a critical saturation (Srg).

For standard relative permeability curves, as the Sg increases from 0.0 to Srg the Krw will remain at the maximum. It will only start to reduce when the Sg > Srg.

However an option can be set in the relative permeability curves which will cause the Krw to drop as soon as Sg > 0. Select this option by selecting the “Krw reduces when Sg>0 (not Sg > Sgr)”.


MBAL 11.0 - IPM 8.00 VC2010 - Material Balance - cbm01.mbi
File Tool Options PVT Input History Matching Production Prediction View Units Help
Add Tank
Add Trans.
Add Well
Connect
Move
Select
ESP
Tank01
Gas
Well Input Data - Well Type Definition
Done
Cancel
Help
Report
Calc
Match IPR
Plot
Match Cone
ESP
Gas
Setup
Inflow Performance
More Inflow
Outflow Performance
Delete Layer
Edit...
Ok
<< Prior
Next >>
Relative Permeabilities
Done
Cancel
Help
Reset
Plot
Copy
Calc

Well: Gas

☐ Disabled

Well Type : Dry Gas Producer

Inflow Performance: Per Phase

Frac Flow Model: Use Rel Perm 1

☐ Layer Disabled

Layers: Tank01

Productivity Index (MMscf/da

Test WGR STB/MMs

Rel Perm. from: Corey Functions

Hysteresis: No

☐ Krw reduces when Sg > 0 (not Sg > Sgr)

	Residual Saturation	End Point	Exponent
	fraction	fraction	
Krw	0.25	0.0001	3
Krg	0.05	0.8	3

Note that this permeability variation is used to correct the IPR calculations in the Production Prediction. It will not affect the material balance calculations other than that the corrected IPR will predict a different rate and hence a different tank pressure. It will not affect the History Matching.

2.5 Reservoir Allocation Tool

2.5.1 Background

One of the major challenges faced during any study that involves wells producing from many layers is the production allocation; that is how much each layer is contributing to the total cumulative observed at the surface. The allocation over time depends on the properties of each layer (inflows) and the pressure depletion of each layer. This could be assumed constant over time, provided that the layers include fluid and rock of the same properties, as well as being of the same size. Neither of these assumptions are in multi-layer systems. Most wells produce from layers which are not of the same size and do not have fluid and rock of the same physical behaviour.

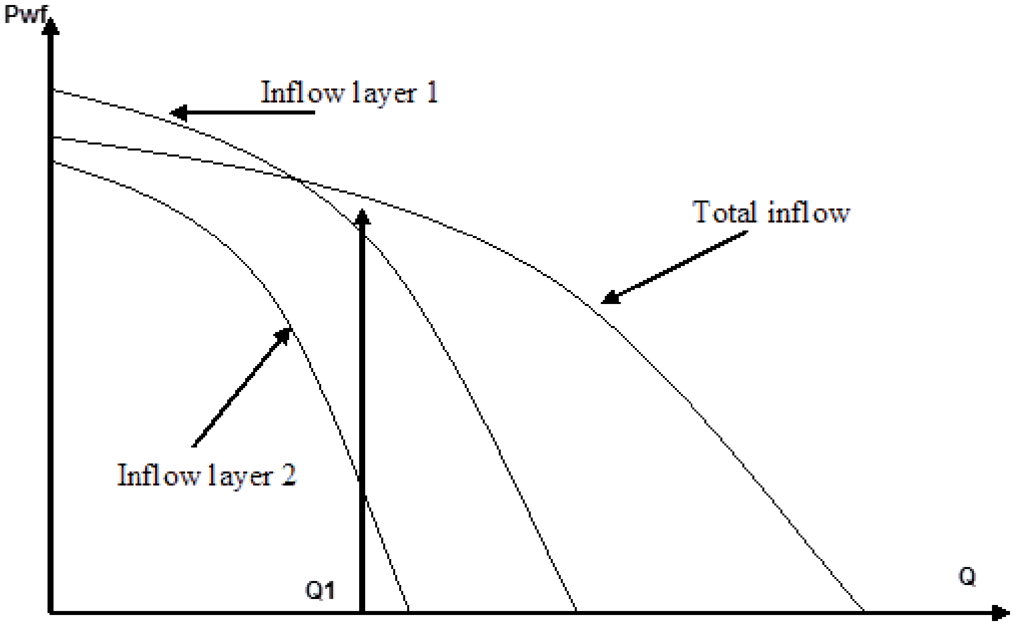
The traditional approach in tackling the allocation problem involves doing the allocation based on a constant K*h for the layers and is used widely in the industry in the absence of any other allocation method.

Petex was not satisfied with this approach and a new allocation technique was developed to account for the actual representation of the inflows as well as the rate of depletion of each layer.

The new technique involves the following steps:

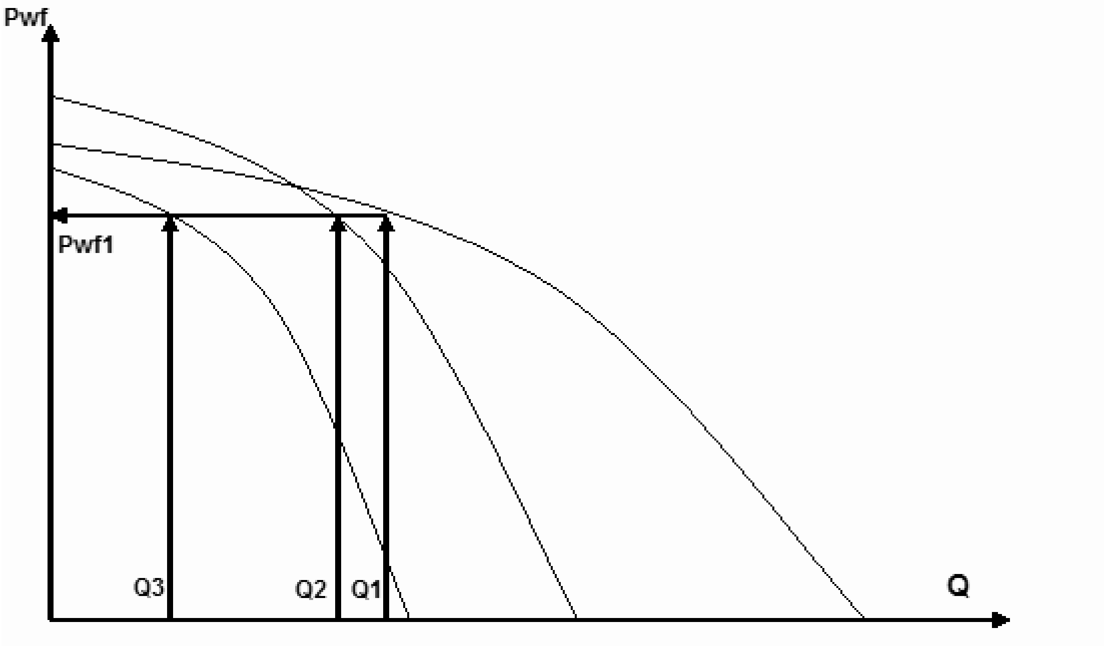
1. Defining the inflow for each layer on a timestep basis

2. Setting up a material balance model that accounts for the rate of depletion which will correct the inflows at each timestep. The method can be best explained by using the following diagrams (not to scale):



Using the reservoir properties, the inflows of the layers producing into the same well can be calculated. In the diagram above and for simplicity, the presence of only two layers was assumed. It is important to note that the IPRs for the layers will be referred to the same datum depth - in most cases the solution node/topmost perforation of top layer. This allows a total/ global IPR to be constructed for the multilayered system from which the total rates measured from the well can be associated.

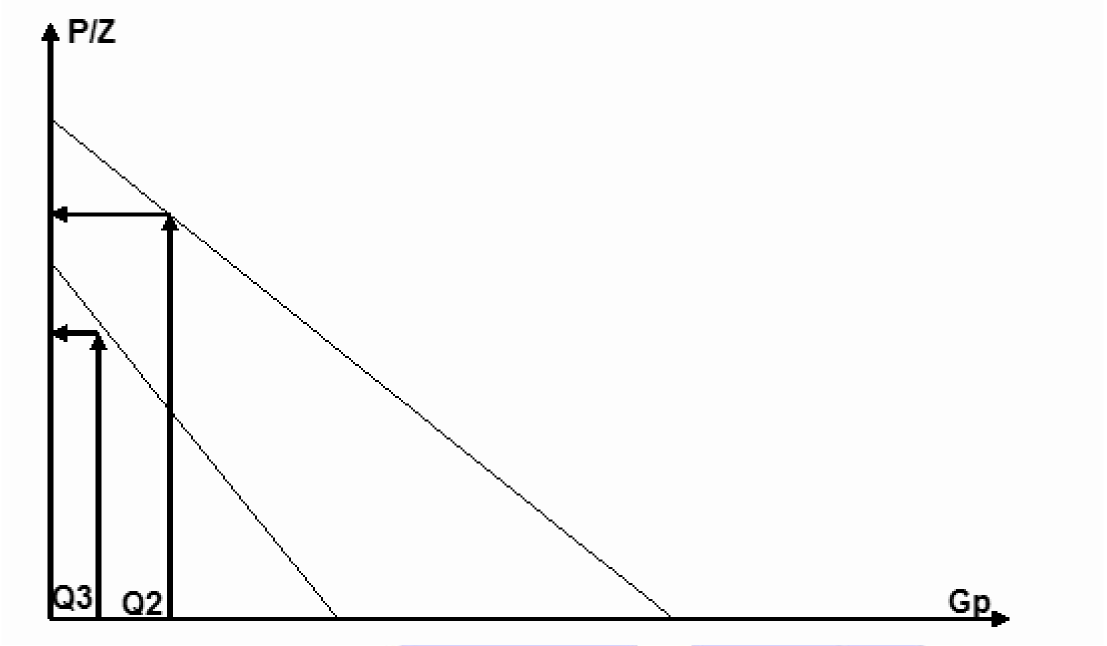
Starting from 'Day 1' of production, the cumulative measured rate for the day is defined as Q_1. Since the IPRs have to be corrected to the same depth, there can only be one Pwf pressure for that rate at the given depth (basic principle of nodal analysis). Therefore, this Pwf can be determined from the total IPR:



As the total IPR is the combined rates of the two individual IPRs, the contributing rates from each layer can in turn be determined from the Pwf. These are defined as Q_2 and Q_3 in the above diagram which represent the allocation for the first day of production.

The next step involves determining the IPRs for the second day. The C and N parameters can be used as for the originally generated IPRs. The third parameter required by this method however, is the reservoir pressure. To do so, a reservoir model as modelled in **MBAL** is therefore needed. This model will account for; the aquifer effect, pore volume compressibility and connate water expansion allowing for a prediction of reservoir pressure with respect to the fluid being withdrawn from the reservoir.

Consider a P/Z diagram for the two layers which would be represented by the following shape:



From the layer production calculated on 'Day 1', the new reservoir pressures can be determined and the new IPRs plotted. The procedure is then repeated and the allocation for each layer throughout the time of the well’s life is determined.

It is important to note the limitations of the method which is basically that the MBAL tanks for the layers have to be used to predict the changes in saturations (for fractional flow) and reservoir pressure over time during the allocation. This means starting with a history matched **MBAL** model which also has history matched fractional flows. However the **MBAL** models actually need the individual layer allocations for the tank history match and fractional flow match. So in theory, the the reservoir model and fractional flows which will be initially used for reservoir allocation will be assumed by user based on knowledge of the project. However, there can then be an iterative procedure between the reservoir allocation tool and material balance until the model converges to a solution thereby coming up with the correct allocation which also represents the reservoir behaviour.

This new method improves on the k*h method due in particular to the following:

- At each time step the model will calculate the current layer rates using the current layer pressures and the input IPR.
- The pressure at the next time step is then calculated using either material balance or decline curve calculations (when "use input tank response" is selected within the model).

2.5.2 Reservoir Allocation Tool Capabilities

The tool can handle:

- Any number of wells and tanks and connection between the wells and tanks.
- Both production and injection wells.
- Oil, gas or condensate reservoirs.
- Production from each layer defined over a scheduled period.

At the beginning of each time step:

- **MBAL** performs a regression to calculate the layer rates that add up to the total well rate while accounting for inflow performance and current tank pressure.
- The fractional flow is calculated either using one of two possible methods:
  1. the relative permeability curves and current saturations
  2. input table of Np/Gp vs. GOR/Wc/etc.
- The fractional flow from each layer is then used to weight the layer productivity to give Qo, Qg and Qw (while always respecting the total well Qo/Qg/Qw).

MBAL then calculates the pressure at the end of the time step taking into account the new cumulative layer rates. This can be done in two ways:

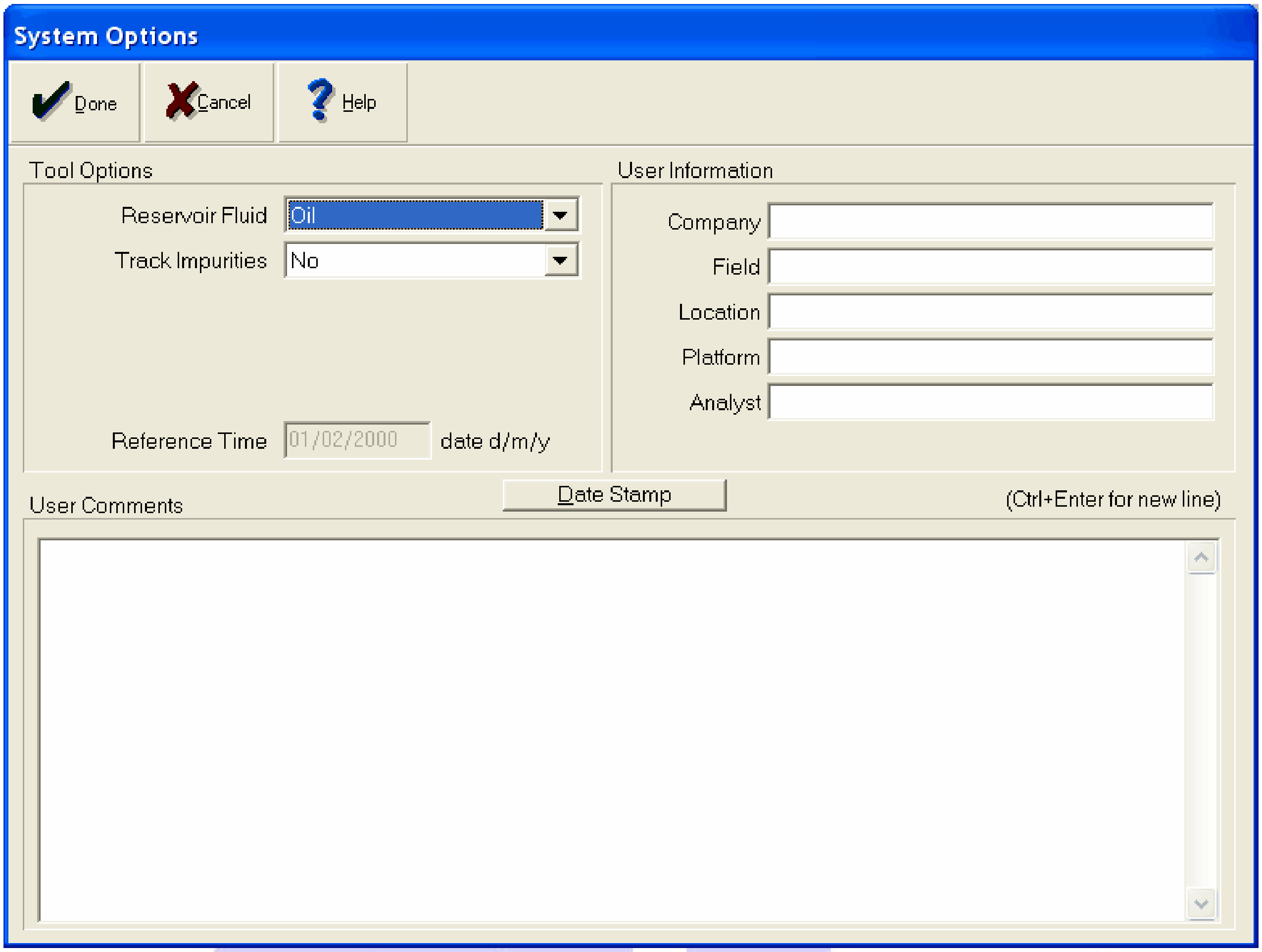
- Using the material balance calculations to calculate the new pressure taking into account the OOIP/OGIP, the aquifer and PVT model.
- Using an input table of Np/Gp vs. pressure to lookup the new pressure.

2.5.3 Graphical Interface

The **Reservoir Allocation** tool uses a graphical interface to build the reservoir and well models. This is essentially the same interface as is used by the material balance tool.

2.5.4 Tool Options

On selecting **Production Allocation** as the analysis tool in the **Tool** menu, go to the **Options** menu to define the primary fluid of the reservoir. This section describes the **Tool Options** section of the **System Options** dialogue box.



Reservoir Fluid: Oil
Track Impurities: No
Reference Time: 01/02/2000 date d/m/y
Company:
Field:
Location:
Platform:
Analyst:
User Comments:

To select an option, click the arrow to the right of the field to display the current choices. To move to the next entry field, click the field to highlight the entry, or use the **TAB** button.

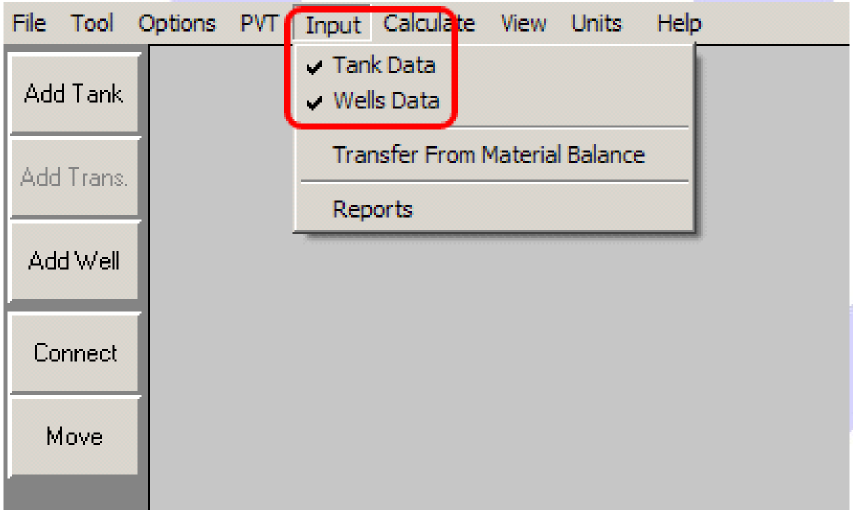
Input Fields

Reservoir Fluid	This tool can handle oil, gas and retrograde condensate fluids. **Oil** – This option models oil reservoirs **Gas** – **(Dry and Wet Gas)** Wet gas is handled under the assumption that condensation occurs at the separator. The liquid is put back into the gas as an equivalent gas quantity. The pressure drop is therefore calculated on the basis of a single phase gas, unless water is present **Retrograde Condensate** – The program uses the retrograde condensate black oil model. These models take into account liquid dropout at different pressure and temperatures

<table>
<tr><td>Track impurities</td><td>CO2, H2S and N2 can be tracked in the model for comparison with measured percentages at the end of the allocation</td></tr>
<tr><td>Reference Time</td><td>The format that time data is displayed in MBAL can be of two types:
<table>
<tr><td>Date</td><td>A calendar date displayed in the format defined by Windows e.g. 23/12/2001 or 02/28/98</td></tr>
<tr><td>Time</td><td>A decimal number of days, weeks, months or years since a reference date</td></tr>
</table>
<p>The format is selected for the time unit type in the Units dialogue.</p>
<p>If days, weeks, months or years (rather than date format) have been selected, this field allows entering the reference date.</p></td></tr>
<tr><td>User Information</td><td>The information for these fields is optional. The general details entered here provide the banner/header information that identify the reservoir in the reports and plots generated by the program</td></tr>
<tr><td>User Comments and Date Stamp</td><td>Space where a log of the updates or changes to the file can be stored. This comments box can also be used to exchange information between users. An unlimited amount of text is allowed.
Press Ctrl+Enter to start a new paragraph.
<p>The comments box can be viewed by either dragging the scroll bar thumb or using the up and down directional arrow keys.</p>
<p>The Date Stamp command adds the current date and time to the User Comments Box</p></td></tr>
</table>

2.5.5 Input Data

The data for this model can be entered from:

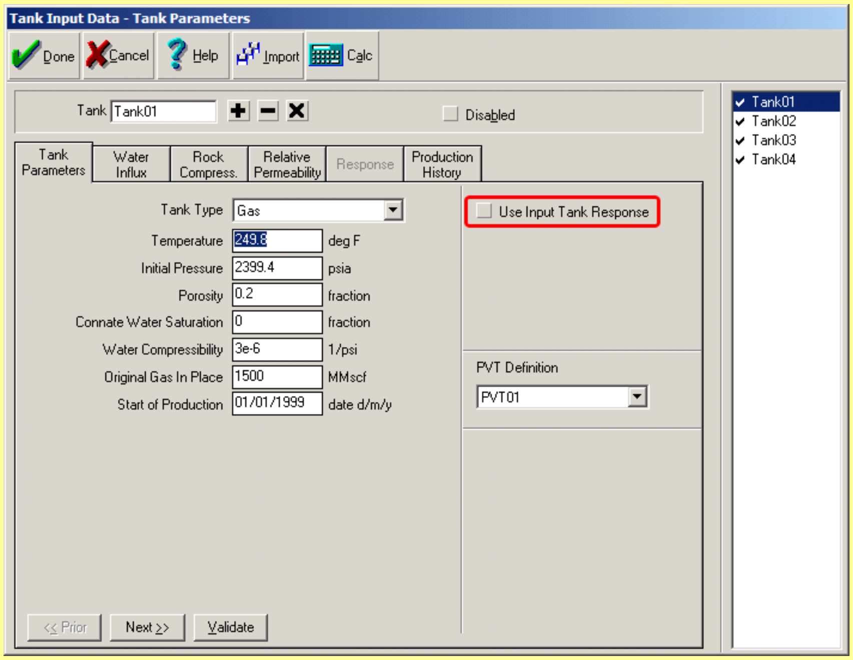

File
Tool
Options
PVT
Input
Calculate
View
Units
Help
✓ Tank Data
✓ Wells Data
Transfer From Material Balance
Reports
Add Tank
Add Trans.
Add Well
Connect
Move

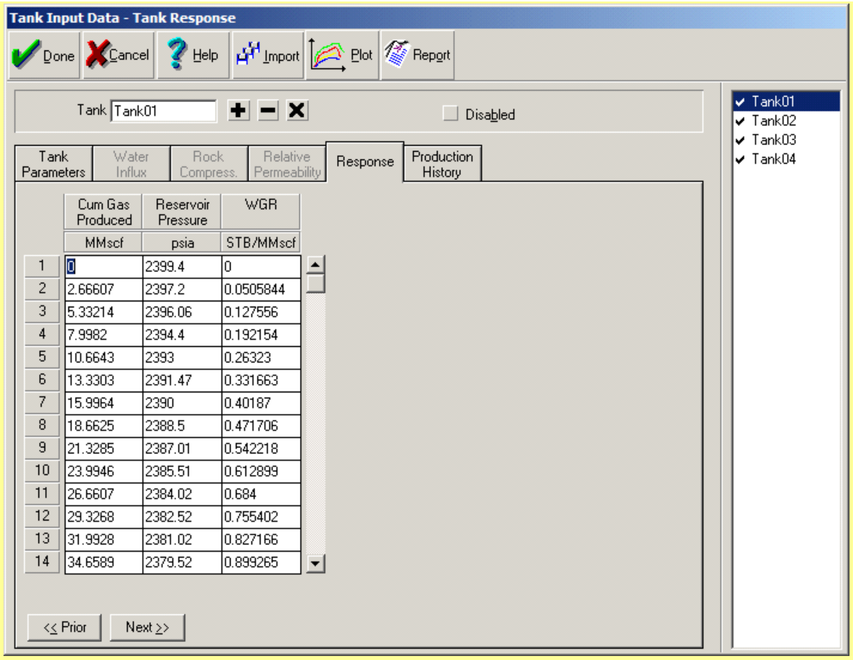
2.5.5.1 Tank Input Data

To access the layer properties dialogue box, choose **Input|Tank Data**.

The dialogue has similar requirements for the tank input 181 as for the material balance tool.

The main differences are:

Tank Parameters Tab	**Use Input Tank Response**  Done Cancel Help Import Calc Tank Parameters Water Influx Rock Compress. Relative Permeability Response Production History << Prior Next >> Validate Tank Input Data - Tank Parameters Tank Tank01 ☐ Disabled ✓ Tank01 ✓ Tank02 ✓ Tank03 ✓ Tank04 Tank Type Gas Temperature 249.8 deg F Initial Pressure 2399.4 psia Porosity 0.2 fraction Connate Water Saturation 0 fraction Water Compressibility 3e-6 1/psi Original Gas In Place 1500 MMscf Start of Production 01/01/1999 date d/m/y ☐ Use Input Tank Response PVT Definition PVT01 This option is available for those wishing to use a table of data to model the time dependant response of the tank. See **Tank Response Input** below for more information. It should not be selected if the material balance calculations are to be used to model how the pressure change in the tank and the fractional flow evolution.
Tank Response Tab	The table entered is used to model the time dependant behaviour of the tank.

<table>
<tr>
<td></td>
<td>

Tank Input Data - Tank Response
Done
Cancel
Help
Import
Plot
Report
Tank
Tank01
Disabled
Tank Parameters
Water Influx
Rock Compress.
Relative Permeability
Response
Production History
<< Prior
Next >>
Tank01
Tank02
Tank03
Tank04

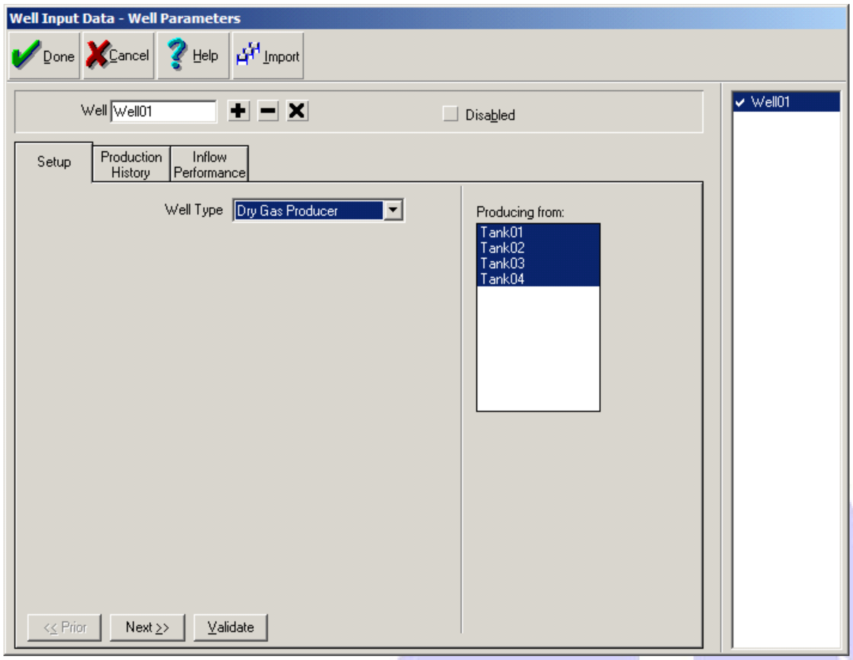
<table>
<tr><th></th><th>Cum Gas Produced</th><th>Reservoir Pressure</th><th>WGR</th></tr>
<tr><th></th><th>MMscf</th><th>psia</th><th>STB/MMscf</th></tr>
<tr><td>1</td><td>0</td><td>2399.4</td><td>0</td></tr>
<tr><td>2</td><td>2.66607</td><td>2397.2</td><td>0.0505844</td></tr>
<tr><td>3</td><td>5.33214</td><td>2396.06</td><td>0.127556</td></tr>
<tr><td>4</td><td>7.9982</td><td>2394.4</td><td>0.192154</td></tr>
<tr><td>5</td><td>10.6643</td><td>2393</td><td>0.26323</td></tr>
<tr><td>6</td><td>13.3303</td><td>2391.47</td><td>0.331663</td></tr>
<tr><td>7</td><td>15.9964</td><td>2390</td><td>0.40187</td></tr>
<tr><td>8</td><td>18.6625</td><td>2388.5</td><td>0.471706</td></tr>
<tr><td>9</td><td>21.3285</td><td>2387.01</td><td>0.542218</td></tr>
<tr><td>10</td><td>23.9946</td><td>2385.51</td><td>0.612899</td></tr>
<tr><td>11</td><td>26.6607</td><td>2384.02</td><td>0.684</td></tr>
<tr><td>12</td><td>29.3268</td><td>2382.52</td><td>0.755402</td></tr>
<tr><td>13</td><td>31.9928</td><td>2381.02</td><td>0.827166</td></tr>
<tr><td>14</td><td>34.6589</td><td>2379.52</td><td>0.899265</td></tr>
</table>

<p>The main column in the table is the cumulative principal fluid. For oil tanks this is Np and for gas/condensate tanks this is Gp.</p>
<p>In the production allocation tool, the rate is recalculated at each time step for each tank. This gives us the Np/Gp at the end of the time step. Once we have the Np/Gp we can then read off the Pressure, GOR, and WGR etc from the table by interpolation.</p>
<p>This tab is only accessible if the Use Input Tank Response option is switched on in the tank parameters tab.</p>
</td>
</tr>
<tr>
<td>Production History Tab</td>
<td>For Production Allocation this is actually OUTPUT data so it does not need to be entered. Once the production allocation calculation has been carried out, the calculated tank history will be presented in this table</td>
</tr>
</table>

2.5.5.2 Well Input Data

To access the well data dialogue box, choose **Input|Well Data**.

The well data dialogue has three tabs:


Well Input Data - Well Parameters
Done
Cancel
Help
Import
Disabled
Setup
Production History
Inflow Performance
Producing from:
<< Prior
Next >>
Validate

Well Well01

Well Type Dry Gas Producer

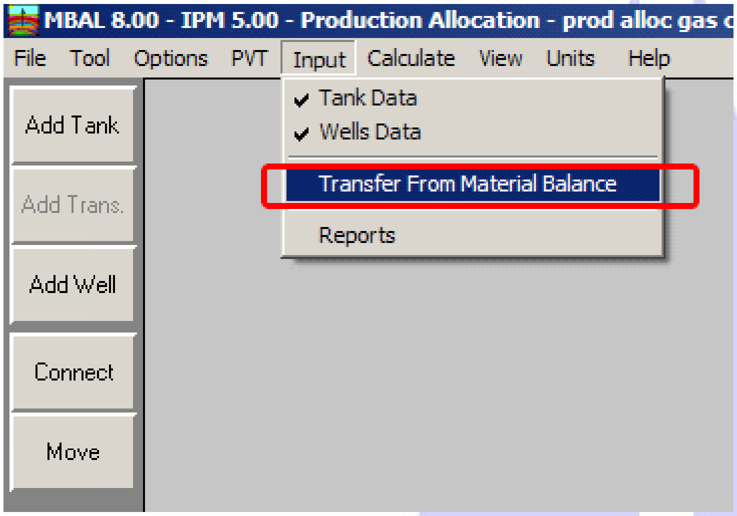
Producing from: Tank01 Tank02 Tank03 Tank04

✓ Well01

Setup Tab	This tab is used to set the well type and which tanks are perforated by the well
Production History Tab	The production data for the well is used to drive the production allocation calculation. The total layer calculated for each well will always respect the input production data. For consistency, pressures can be entered in the production data. The inputs are the same as the production history tab in the 'Material Balance History Well Production History' tab
Inflow Performance Tab	This tab is used to enter the inflow performance for each layer. This is used to distribute the total well rate between layers. This tab has nearly all the same inputs as the material balance prediction well inflow tab

2.5.5.3 Transfer from Material Balance

This option can be found under:


MBAL 8.00 - IPM 5.00 - Production Allocation - prod alloc gas c
File
Tool
Options
PVT
Input
Calculate
View
Units
Help
Tank Data
Wells Data
Transfer From Material Balance
Reports
Add Tank
Add Trans.
Add Well
Connect
Move

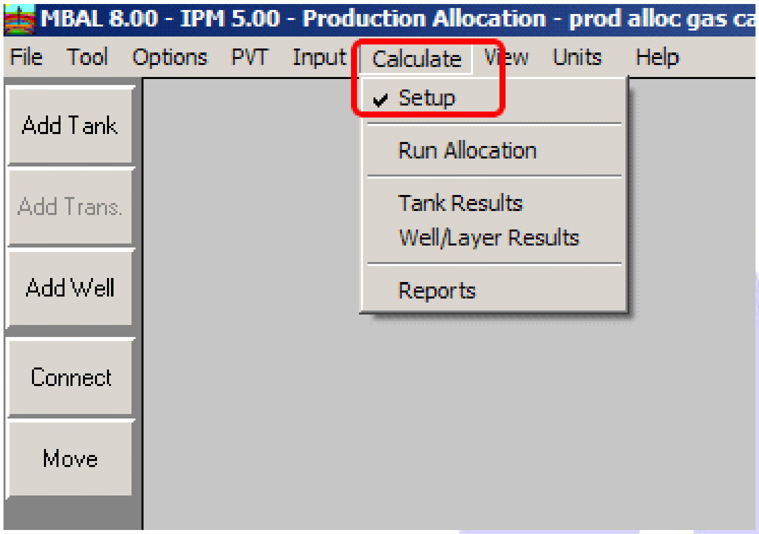
The input data model for the production allocation tool and the material balance tool have many similarities. Both of the tools use tanks and wells which allows the whole data input set from the material balance tool to be transferred into the production allocation tool.

On selecting the menu options, the user will be required to confirm that all the existing production allocation tool input data can be overwritten by the material balance tool data.

All the tank and PVT data will then be copied and brought across from the material balance tool. In addition, the prediction wells will be copied from the material balance tool and the connections between wells and tanks will be rebuilt.

2.5.6 Calculations

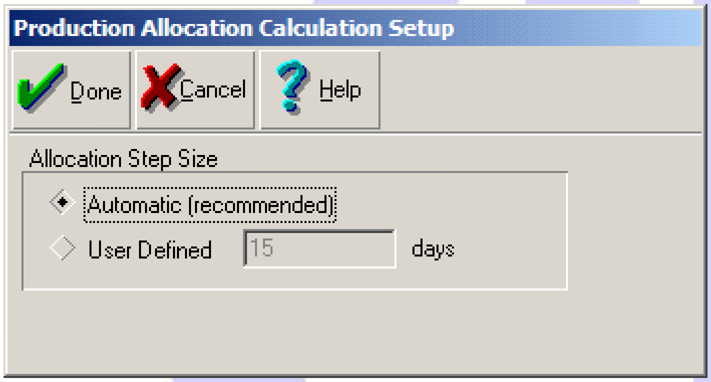
Once the model is set up, then the calculations can be performed from the calculation menu:


MBAL 8.00 - IPM 5.00 - Production Allocation - prod alloc gas ca
File
Tool
Options
PVT
Input
Calculate
View
Units
Help
Setup
Run Allocation
Tank Results
Well/Layer Results
Reports
Add Tank
Add Trans.
Add Well
Connect
Move

2.5.6.1 Setup

To access the setup dialogue box, select **Calculations|Setup** menu item.

This dialogue is used to enter the setup parameters for the production allocation calculation:


Production Allocation Calculation Setup
Done
Cancel
Help

Allocation Step Size

● Automatic (recommended)

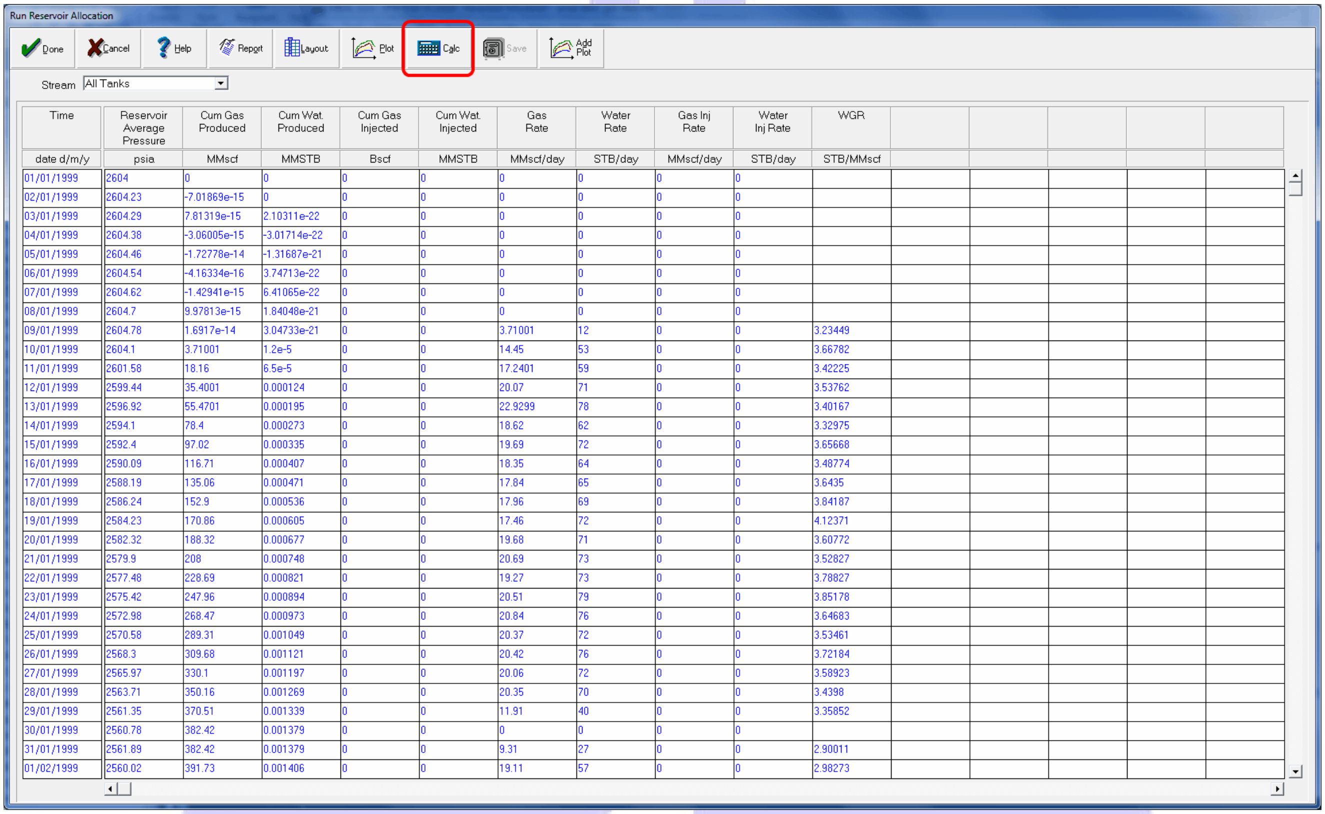
○ User Defined 15 days

Allocation Step Size	Set the size of the internal time steps used in the calculation. A smaller time step can be used to more accurately predict cases with larger aquifers. Larger time steps will speed up the calculation. If this option is left to automatic, then **MBAL** will use the default time step of 15 days. Note that even if a small internal time step is used, the results will only be reported at the time steps defined in the well production history

2.5.6.2 Run Allocation

This dialogue box is used to run a production allocation as described at the beginning of the chapter.

Selecting the “Calc” button will allow the allocation to be carried out:



Stream: All Tanks

Time	Reservoir Average Pressure	Cum Gas Produced	Cum Wat. Produced	Cum Gas Injected	Cum Wat. Injected	Gas Rate	Water Rate	Gas Inj Rate	Water Inj Rate	WGR
date d/m/y	psia	MMscf	MMSTB	Bscf	MMSTB	MMscf/day	STB/day	MMscf/day	STB/day	STB/MMscf
01/01/1999	2604	0	0	0	0	0	0	0	0	
02/01/1999	2604.23	-7.01869e-15	0	0	0	0	0	0	0	
03/01/1999	2604.29	7.81319e-15	2.10311e-22	0	0	0	0	0	0	
04/01/1999	2604.38	-3.06005e-15	-3.01714e-22	0	0	0	0	0	0	
05/01/1999	2604.46	-1.72778e-14	-1.31687e-21	0	0	0	0	0	0	
06/01/1999	2604.54	-4.16334e-16	3.74713e-22	0	0	0	0	0	0	
07/01/1999	2604.62	-1.42941e-15	6.41065e-22	0	0	0	0	0	0	
08/01/1999	2604.7	9.97813e-15	1.84048e-21	0	0	0	0	0	0	
09/01/1999	2604.78	1.6917e-14	3.04733e-21	0	0	3.71001	12	0	0	3.23449
10/01/1999	2604.1	3.71001	1.2e-5	0	0	14.45	53	0	0	3.66782
11/01/1999	2601.58	18.16	6.5e-5	0	0	17.2401	59	0	0	3.42225
12/01/1999	2599.44	35.4001	0.000124	0	0	20.07	71	0	0	3.53762
13/01/1999	2596.92	55.4701	0.000195	0	0	22.9299	78	0	0	3.40167
14/01/1999	2594.1	78.4	0.000273	0	0	18.62	62	0	0	3.32975
15/01/1999	2592.4	97.02	0.000335	0	0	19.69	72	0	0	3.65668
16/01/1999	2590.09	116.71	0.000407	0	0	18.35	64	0	0	3.48774
17/01/1999	2588.19	135.06	0.000471	0	0	17.84	65	0	0	3.6435
18/01/1999	2586.24	152.9	0.000536	0	0	17.96	69	0	0	3.84187
19/01/1999	2584.23	170.86	0.000605	0	0	17.46	72	0	0	4.12371
20/01/1999	2582.32	188.32	0.000677	0	0	19.68	71	0	0	3.60772
21/01/1999	2579.9	208	0.000748	0	0	20.69	73	0	0	3.52827
22/01/1999	2577.48	228.69	0.000821	0	0	19.27	73	0	0	3.78827
23/01/1999	2575.42	247.96	0.000894	0	0	20.51	79	0	0	3.85178
24/01/1999	2572.98	268.47	0.000973	0	0	20.84	76	0	0	3.64683
25/01/1999	2570.58	289.31	0.001049	0	0	20.37	72	0	0	3.53461
26/01/1999	2568.3	309.68	0.001121	0	0	20.42	76	0	0	3.72184
27/01/1999	2565.97	330.1	0.001197	0	0	20.06	72	0	0	3.58923
28/01/1999	2563.71	350.16	0.001269	0	0	20.35	70	0	0	3.4398
29/01/1999	2561.35	370.51	0.001339	0	0	11.91	40	0	0	3.35852
30/01/1999	2560.78	382.42	0.001379	0	0	0	0	0	0	
31/01/1999	2561.89	382.42	0.001379	0	0	9.31	27	0	0	2.90011
01/02/1999	2560.02	391.73	0.001406	0	0	19.11	57	0	0	2.98273

On entering this dialogue, the results of the last allocation will be displayed. The scroll bars to the bottom and right of the dialogue box allowing the user to browse through the calculations.

This dialogue can also be used to display other results. Each set of results is stored in a **stream** . There is only one stream always present called **All Tanks** which is the latest calculation.

Copies of the current production prediction calculations can be made using the **Save** button. This will create a new stream.

To change the stream displayed, change the selection in the **stream** combo-box at the top left of the dialogue.

Within each stream there are additional items called **sheets**. Each sheet corresponds to a tank. The user can also select a sheet to display in the streams combo-box. The results displayed if the stream is selected (rather than one of its sheets) are the consolidated results i.e. the cumulative results from all the tanks.

Rates are reported in two ways in the prediction:

Cumulative rates	This is the total rate produced up to the time at which the rate is reported
Rate	This is the rate at the time reported

Click the **Calc** button to start the production allocation calculation. After the calculation finishes, the program will automatically transfer the cumulative rates calculated for each tank into the tank production history in the tank objects.

When the calculation is finished, the program will automatically transfer the cumulative rates calculated for each tank into the tank production history in the tank objects.

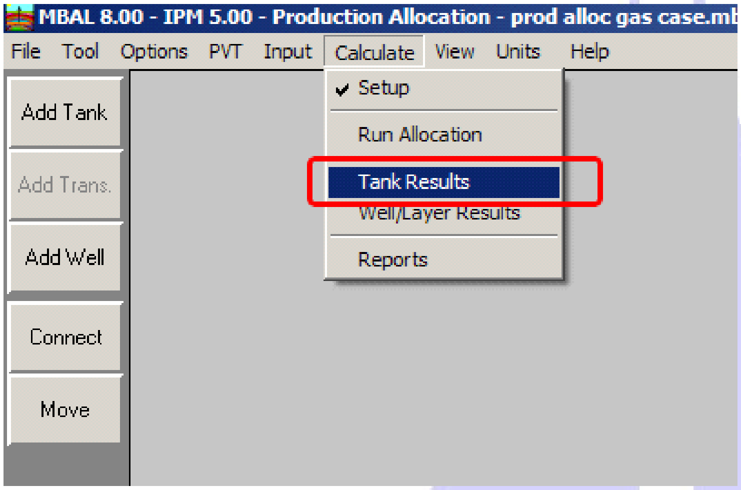
Command Buttons

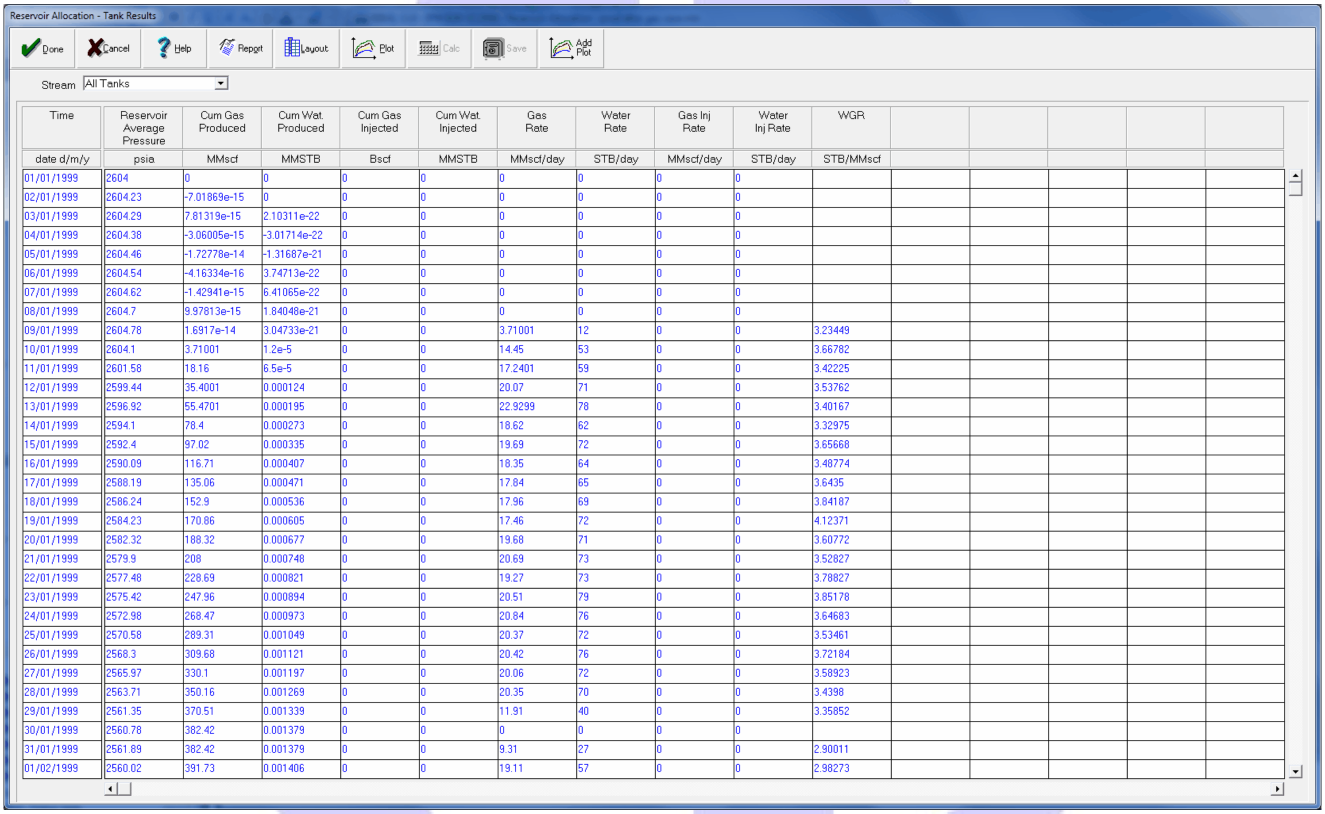
Report	Allows reporting of the currently displayed stream/sheet to a file, clipboard or printer
Layout	Allows the user to display a selection of particular variables of interest in a few of the calculation result columns. These column selections are also used by the reporting facility
Plot	Displays a plot of up to two variables from one or more streams or sheets
Calc	Click this button to start a new allocation. A small progress window with an Abort button will appear in the top right hand corner of the screen. Press the Abort button at any time to stop the calculation
Save	Use this button to save the current prediction results in a new stream. See Saving Allocation Results for more information

For more information about the calculations see Reservoir Allocation Overview.

2.5.6.3 Tank Results

This dialogue box is used to display the tank and results from a production allocation:


MBAL 8.00 - IPM 5.00 - Production Allocation - prod alloc gas case.mb
File
Tool
Options
PVT
Input
Calculate
View
Units
Help
Add Tank
Add Trans.
Add Well
Connect
Move
Setup
Run Allocation
Tank Results
Well/Layer Results
Reports


Reservoir Allocation - Tank Results
Done
Cancel
Help
Report
Layout
Plot
Calc
Save
Add Plot

Stream: All Tanks

Time	Reservoir Average Pressure	Cum Gas Produced	Cum Wat. Produced	Cum Gas Injected	Cum Wat. Injected	Gas Rate	Water Rate	Gas Inj Rate	Water Inj Rate	WGR
date d/m/y	psia	MMscf	MMSTB	Bscf	MMSTB	MMscf/day	STB/day	MMscf/day	STB/day	STB/MMscf
01/01/1999	2604	0	0	0	0	0	0	0	0	
02/01/1999	2604.23	-7.01869e-15	0	0	0	0	0	0	0	
03/01/1999	2604.29	7.81319e-15	2.10311e-22	0	0	0	0	0	0	
04/01/1999	2604.38	-3.06005e-15	-3.01714e-22	0	0	0	0	0	0	
05/01/1999	2604.46	-1.72778e-14	-1.31687e-21	0	0	0	0	0	0	
06/01/1999	2604.54	-4.16334e-16	3.74713e-22	0	0	0	0	0	0	
07/01/1999	2604.62	-1.42941e-15	6.41065e-22	0	0	0	0	0	0	
08/01/1999	2604.7	9.97813e-15	1.84048e-21	0	0	0	0	0	0	
09/01/1999	2604.78	1.6917e-14	3.04733e-21	0	0	3.71001	12	0	0	3.23449
10/01/1999	2604.1	3.71001	1.2e-5	0	0	14.45	53	0	0	3.66782
11/01/1999	2601.58	18.16	6.5e-5	0	0	17.2401	59	0	0	3.42225
12/01/1999	2599.44	35.4001	0.000124	0	0	20.07	71	0	0	3.53762
13/01/1999	2596.92	55.4701	0.000195	0	0	22.9299	78	0	0	3.40167
14/01/1999	2594.1	78.4	0.000273	0	0	18.62	62	0	0	3.32975
15/01/1999	2592.4	97.02	0.000335	0	0	19.69	72	0	0	3.65668
16/01/1999	2590.09	116.71	0.000407	0	0	18.35	64	0	0	3.48774
17/01/1999	2588.19	135.06	0.000471	0	0	17.84	65	0	0	3.6435
18/01/1999	2586.24	152.9	0.000536	0	0	17.96	69	0	0	3.84187
19/01/1999	2584.23	170.86	0.000605	0	0	17.46	72	0	0	4.12371
20/01/1999	2582.32	188.32	0.000677	0	0	19.68	71	0	0	3.60772
21/01/1999	2579.9	208	0.000748	0	0	20.69	73	0	0	3.52827
22/01/1999	2577.48	228.69	0.000821	0	0	19.27	73	0	0	3.78827
23/01/1999	2575.42	247.96	0.000894	0	0	20.51	79	0	0	3.85178
24/01/1999	2572.98	268.47	0.000973	0	0	20.84	76	0	0	3.64683
25/01/1999	2570.58	289.31	0.001049	0	0	20.37	72	0	0	3.53461
26/01/1999	2568.3	309.68	0.001121	0	0	20.42	76	0	0	3.72184
27/01/1999	2565.97	330.1	0.001197	0	0	20.06	72	0	0	3.58923
28/01/1999	2563.71	350.16	0.001269	0	0	20.35	70	0	0	3.4398
29/01/1999	2561.35	370.51	0.001339	0	0	11.91	40	0	0	3.35852
30/01/1999	2560.78	382.42	0.001379	0	0	0	0	0	0	
31/01/1999	2561.89	382.42	0.001379	0	0	9.31	27	0	0	2.90011
01/02/1999	2560.02	391.73	0.001406	0	0	19.11	57	0	0	2.98273

This dialogue box is used to display the tank and results from a reservoir allocation. For more information about the calculations see Reservoir Allocation Overview.

On entering this dialogue, the results of the last allocation will be displayed. The scroll bars to the bottom and right of the dialogue box allow the user to browse through the calculations.

This dialogue can also be used to display other results. Each set of results is stored in a **stream**

. There is always one streams present by default 'All Tanks' (the last calculation performed)

To change the stream displayed, change the selection in the **stream** combo-box at the top left of the dialogue.

Within each stream there are additional items called **sheets**. Each sheet corresponds to a tank. It is also possible to select a sheet to display in the streams combo-box. The results displayed if a stream is selected (rather than one of its sheets) are the consolidated results i.e. the cumulative results from all the tanks.

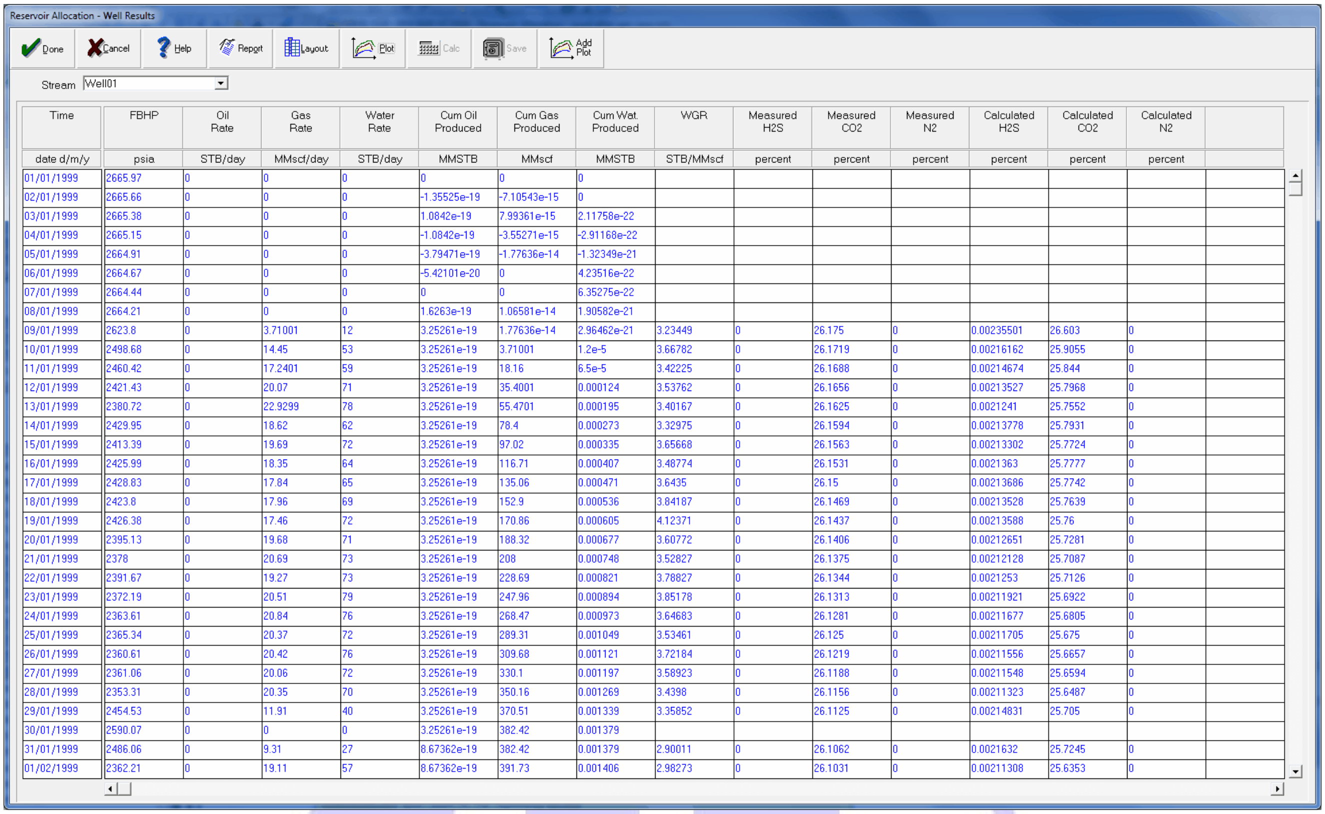
Command Buttons

Report	Allows reporting of the currently displayed stream/sheet to a file, clipboard or printer
Layout	Allows the user to display the variables of interest in the calculation results. These column selections are also used by the reporting facility
Plot	Displays a plot of up to two variables from one or more streams or sheets

The results can be plotted.

2.5.6.4 Well/Layer Results

This dialogue box displays the well results of the last allocation calculation. To browse through the results, use the scroll bars to the right and bottom of the screen.



Stream Well01

Time	FBHP	Oil Rate	Gas Rate	Water Rate	Cum Oil Produced	Cum Gas Produced	Cum Wat. Produced	WGR	Measured H2S	Measured CO2	Measured N2	Calculated H2S	Calculated CO2	Calculated N2
date d/m/y	psia	STB/day	MMscf/day	STB/day	MMSTB	MMscf	MMSTB	STB/MMscf	percent	percent	percent	percent	percent	percent
01/01/1999	2665.97	0	0	0	0	0	0							
02/01/1999	2665.66	0	0	0	-1.35525e-19	-7.10543e-15	0							
03/01/1999	2665.38	0	0	0	1.0842e-19	7.99361e-15	2.11758e-22							
04/01/1999	2665.15	0	0	0	-1.0842e-19	-3.55271e-15	-2.91168e-22							
05/01/1999	2664.91	0	0	0	-3.79471e-19	-1.77636e-14	-1.32349e-21							
06/01/1999	2664.67	0	0	0	-5.42101e-20	0	4.23516e-22							
07/01/1999	2664.44	0	0	0	0	0	6.35275e-22							
08/01/1999	2664.21	0	0	0	1.6263e-19	1.06581e-14	1.90582e-21							
09/01/1999	2623.8	0	3.71001	12	3.25261e-19	1.77636e-14	2.96462e-21	3.23449	0	26.175	0	0.00235501	26.603	0
10/01/1999	2498.68	0	14.45	53	3.25261e-19	3.71001	1.2e-5	3.66782	0	26.1719	0	0.00216162	25.9055	0
11/01/1999	2460.42	0	17.2401	59	3.25261e-19	18.16	6.5e-5	3.42225	0	26.1688	0	0.00214674	25.844	0
12/01/1999	2421.43	0	20.07	71	3.25261e-19	35.4001	0.000124	3.53762	0	26.1656	0	0.00213527	25.7968	0
13/01/1999	2380.72	0	22.9299	78	3.25261e-19	55.4701	0.000195	3.40167	0	26.1625	0	0.0021241	25.7552	0
14/01/1999	2429.95	0	18.62	62	3.25261e-19	78.4	0.000273	3.32975	0	26.1594	0	0.00213778	25.7931	0
15/01/1999	2413.39	0	19.69	72	3.25261e-19	97.02	0.000335	3.65668	0	26.1563	0	0.00213302	25.7724	0
16/01/1999	2425.99	0	18.35	64	3.25261e-19	116.71	0.000407	3.48774	0	26.1531	0	0.0021363	25.7777	0
17/01/1999	2428.83	0	17.84	65	3.25261e-19	135.06	0.000471	3.6435	0	26.15	0	0.00213686	25.7742	0
18/01/1999	2423.8	0	17.96	69	3.25261e-19	152.9	0.000536	3.84187	0	26.1469	0	0.00213528	25.7639	0
19/01/1999	2426.38	0	17.46	72	3.25261e-19	170.86	0.000605	4.12371	0	26.1437	0	0.00213588	25.76	0
20/01/1999	2395.13	0	19.68	71	3.25261e-19	188.32	0.000677	3.60772	0	26.1406	0	0.00212651	25.7281	0
21/01/1999	2378	0	20.69	73	3.25261e-19	208	0.000748	3.52827	0	26.1375	0	0.00212128	25.7087	0
22/01/1999	2391.67	0	19.27	73	3.25261e-19	228.69	0.000821	3.78827	0	26.1344	0	0.0021253	25.7126	0
23/01/1999	2372.19	0	20.51	79	3.25261e-19	247.96	0.000894	3.85178	0	26.1313	0	0.00211921	25.6922	0
24/01/1999	2363.61	0	20.84	76	3.25261e-19	268.47	0.000973	3.64683	0	26.1281	0	0.00211677	25.6805	0
25/01/1999	2365.34	0	20.37	72	3.25261e-19	289.31	0.001049	3.53461	0	26.125	0	0.00211705	25.675	0
26/01/1999	2360.61	0	20.42	76	3.25261e-19	309.68	0.001121	3.72184	0	26.1219	0	0.00211556	25.6657	0
27/01/1999	2361.06	0	20.06	72	3.25261e-19	330.1	0.001197	3.58923	0	26.1188	0	0.00211548	25.6594	0
28/01/1999	2353.31	0	20.35	70	3.25261e-19	350.16	0.001269	3.4398	0	26.1156	0	0.00211323	25.6487	0
29/01/1999	2454.53	0	11.91	40	3.25261e-19	370.51	0.001339	3.35852	0	26.1125	0	0.00214831	25.705	0
30/01/1999	2590.07	0	0	0	3.25261e-19	382.42	0.001379							
31/01/1999	2486.06	0	9.31	27	8.67362e-19	382.42	0.001379	2.90011	0	26.1062	0	0.0021632	25.7245	0
01/02/1999	2362.21	0	19.11	57	8.67362e-19	391.73	0.001406	2.98273	0	26.1031	0	0.00211308	25.6353	0

Select the well to be displayed from the **Stream** combo-box.

If a well has more than one layer (i.e. connection to a tank), then the different layers will be shown as sheets. In this case, if the stream (rather than one of the sheets) is selected, the consolidate well results will be displayed i.e. the cumulative results of all layers in that well.

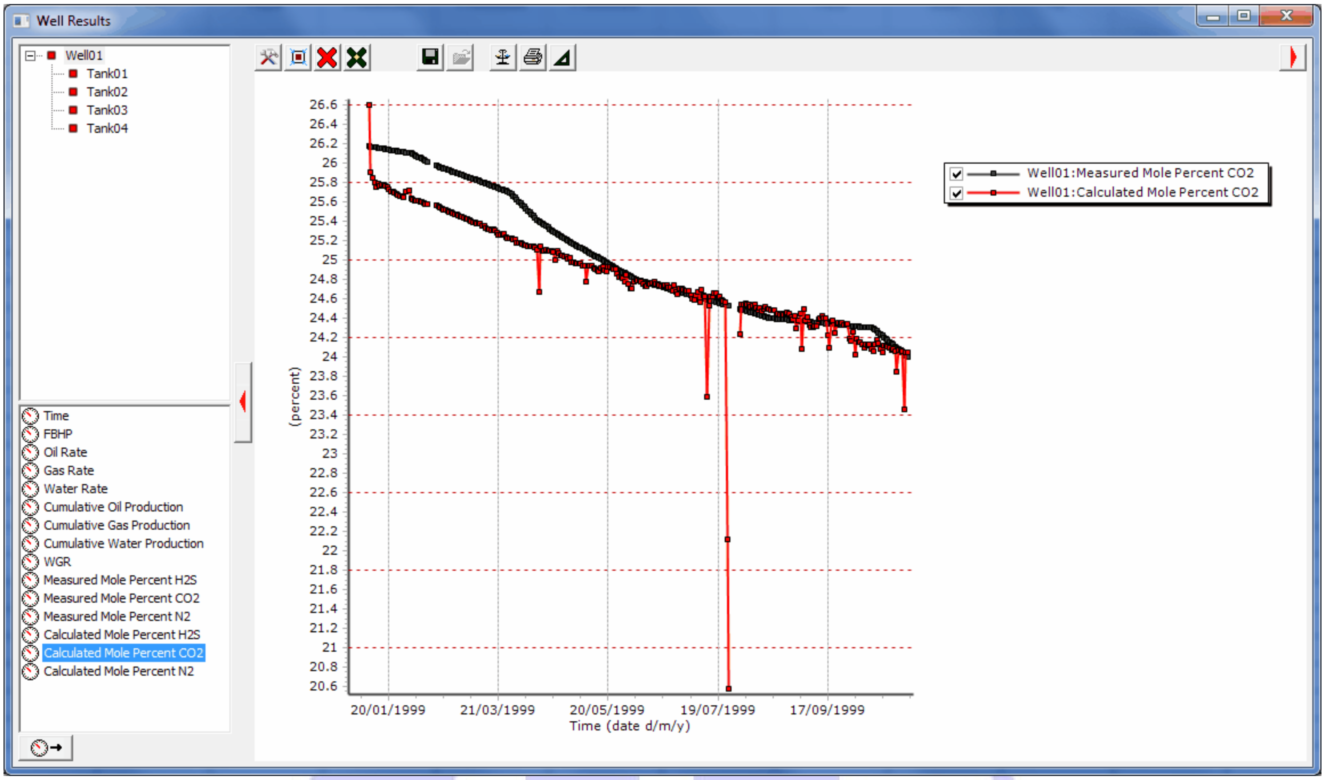
In the case where the calculated and measured CO2 content of the stream needs to be compared, this can be done from the well results option. From the plot variables, the measured and calculated CO2 content can be selected for viewing.

Command Buttons

Report	Allows reporting of the currently displayed stream/sheet to a file, clipboard or printer
Layout	Allows the user to display the variables of interest in the calculation results. These column selections are also used by the reporting facility
Plot	Displays a plot of up to two variables from one or more streams or sheets

Example

In cases in which the calculated and measured CO2 content of the stream need to be compared, the well results option will provide the values. From the plot variables, the measured and calculated CO2 content can be selected for viewing:


Well Results
Well01
Tank01
Tank02
Tank03
Tank04
Time
FBHP
Oil Rate
Gas Rate
Water Rate
Cumulative Oil Production
Cumulative Gas Production
Cumulative Water Production
WGR
Measured Mole Percent H2S
Measured Mole Percent CO2
Measured Mole Percent N2
Calculated Mole Percent H2S
Calculated Mole Percent CO2
Calculated Mole Percent N2
(percent)
26.6
26.4
26.2
26
25.8
25.6
25.4
25.2
25
24.8
24.6
24.4
24.2
24
23.8
23.6
23.4
23.2
23
22.8
22.6
22.4
22.2
22
21.8
21.6
21.4
21.2
21
20.8
20.6
20/01/1999
21/03/1999
20/05/1999
19/07/1999
17/09/1999
Time (date d/m/y)
☑ Well01:Measured Mole Percent CO2
☑ Well01:Calculated Mole Percent CO2

In the case above, the two do not match. Therefore, the GIIP or IPR if the layers need to be adjusted till a match between the measured and calculated values are obtained. This is a powerful quality check on the initial assumptions used to build the model.

2.6 Monte-Carlo Technique

2.6.1 Program Functions

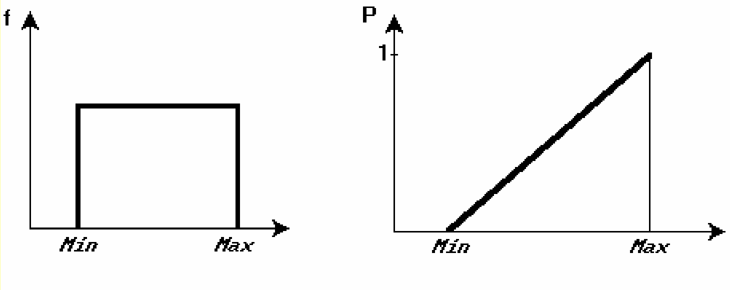
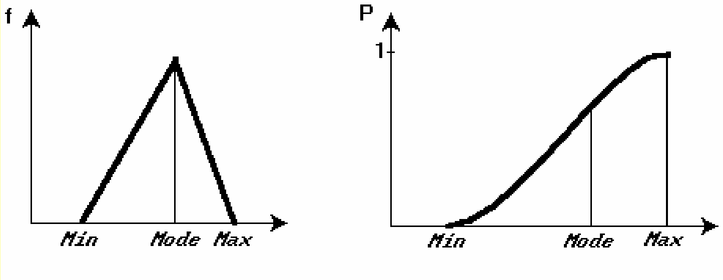
The Monte-Carlo technique is used to evaluate the hydrocarbons in place. Each of the parameters involved in the calculation of reserves; the PVT properties and pore volume are represented by statistical distributions.

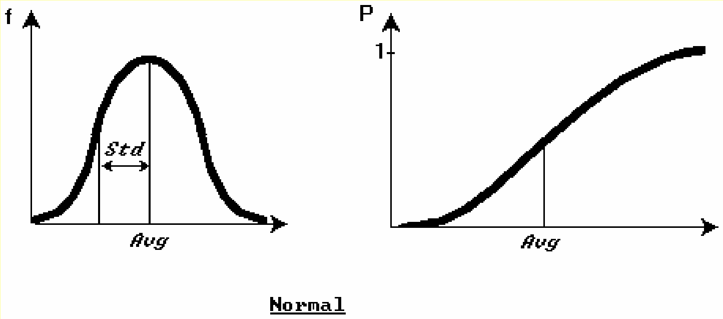
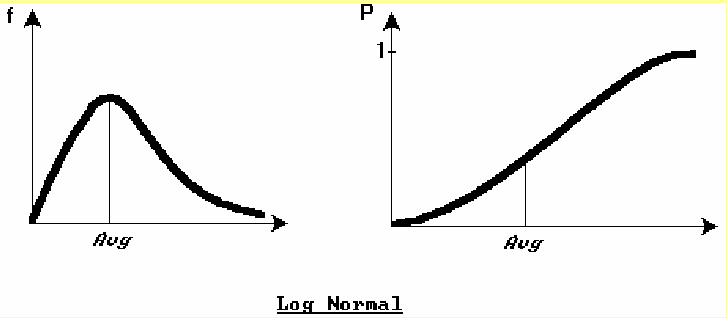
Depending on the number of cases (NC) chosen by the user, the program generates a series of NC values of equal probability for each of the parameters used in the hydrocarbons in place calculation. The NC values of each parameter are then cross-multiplied creating a distribution of values for the hydrocarbons in place. The results are presented in the form of a histogram.

The probability of Swc and porosity are linked to reflect physical reality. If the porosity is near the bottom of the probability range, the Swc will be weighted to be more likely to be near the bottom of the range. Similarly if the porosity is near the top of the range, the Swc will be weighted to be near the top of the range. The same method is used to link the GOR and oil gravity.

2.6.2 Technical Background

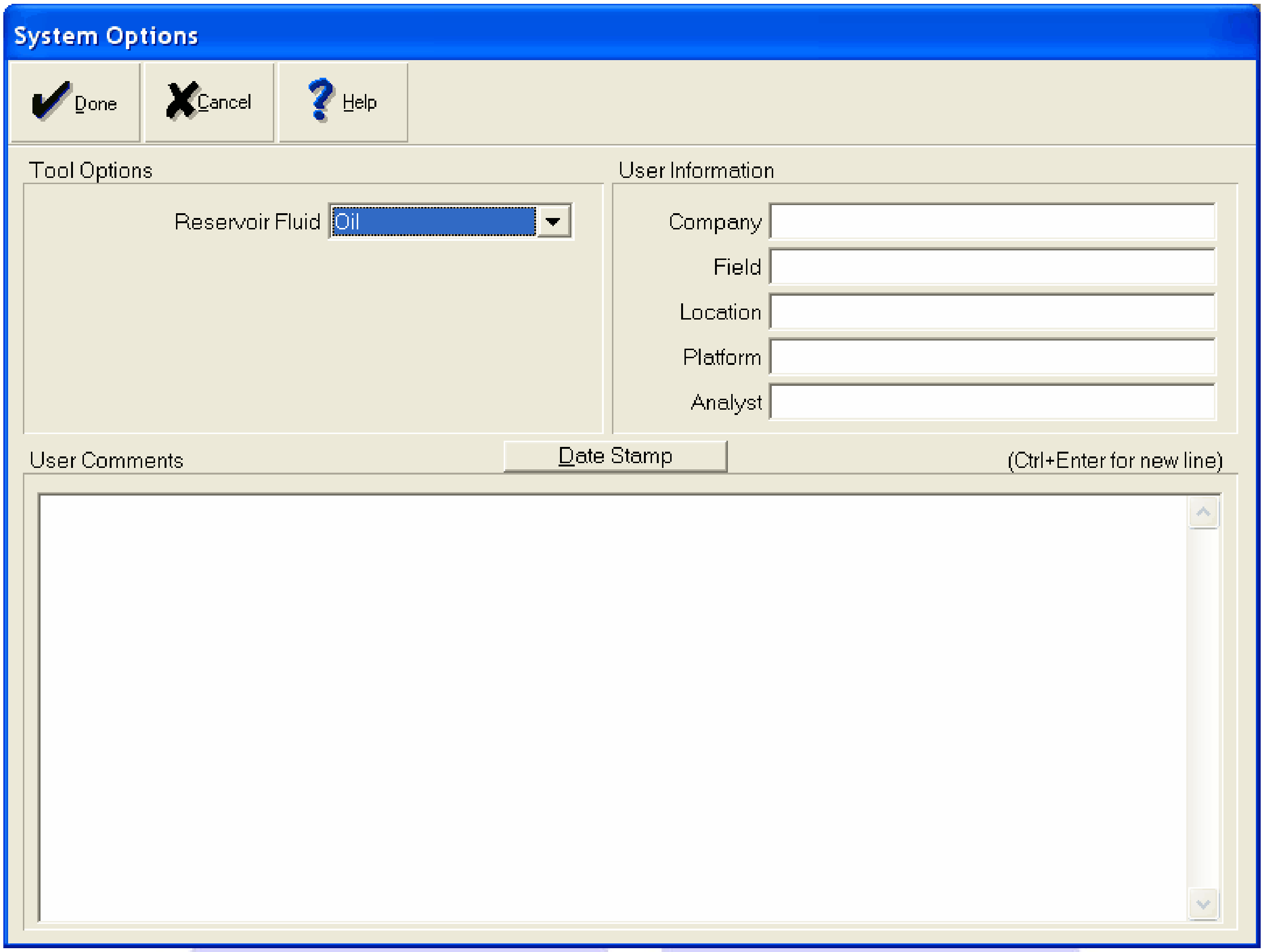
The program supports five types of statistical distributions:
In the definitions below represents the distribution relative frequency and P the distribution cumulative probability.

Fixed Value	Value = Constant
Uniform **Distribution**	This distribution is defined by a minimum (Min) and maximum (Max) value with an equal probability for all values between these 2 extremes. Value = Min + (Min - Max) *Probability  Uniform
Triangular **Distribution**	This distribution is defined by a minimum, maximum and mode value with: At value Mode: Pmod e = (Mode - Min)/(Max - Min) If P < Pmode: $Value = Min + (Mode - Min) * \sqrt{\frac{P}{P \bmod e}}$ If P > Pmode: $Value = Max - (Max - Mode) * \sqrt{\frac{1 - P}{1 - P \bmod e}}$  Triangular

Normal Distribution	This distribution is defined by an average (Avg) and a standard deviation (Std) with: $Value = Avg + Std * \left(\sqrt{Ln\left(\frac{1}{p2}\right)} \right)$ 
Log Normal Distribution	This distribution is defined by an average (Avg) and a standard deviation (Std) with: $\text{Value} = \exp(\log(\text{Avg})) + \log\left(1 + \frac{\text{Std}}{\text{Avg}}\right) * \left(\sqrt{\text{Ln}(1/\text{p2})} - (\ )\right)$ 

2.6.3 Tool Options

On selecting Monte-Carlo as the analysis tool in the **Tool** menu, go to the **Options** menu to define the primary fluid of the reservoir. This section describes the 'Tool Options' section of the System Options dialogue box.


System Options
Done
Cancel
Help
Tool Options
User Information
Company
Field
Location
Platform
Analyst
User Comments
Date Stamp
(Ctrl+Enter for new line)

Reservoir Fluid: Oil

To select an option, click the arrow to the right of the field to display the current choices. To move to the next entry field, click the field to highlight the entry, or use the **TAB** button.

Input Fields

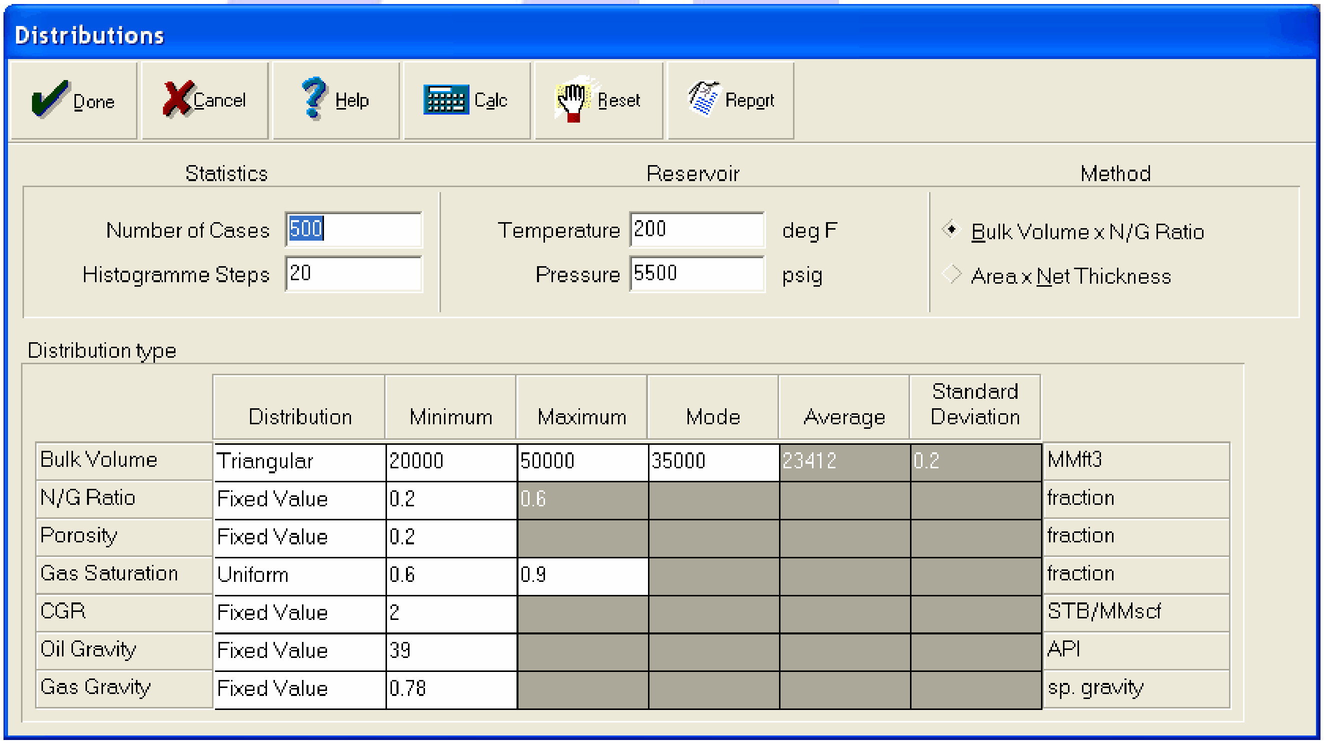
Reservoir Fluid	**Oil**	This option uses traditional black oil models for which four correlations are available. The parameters for these correlations can be changed to match real data using a non-linear regression
	Gas	*(Dry and Wet Gas)* Wet gas is handled under the assumption that condensation occurs at the separator. The liquid is put back into the gas as an equivalent gas quantity. The pressure drop is therefore calculated on the basis of a single phase gas, unless water is present
	Retrograde	**MBAL** uses the retrograde condensate black oil model. The regression allows the matching of PVT

<table>
<tr><td></td><td><table><tr><td>Condensate</td><td>data to real data to be carried out. These models take into account liquid dropout at different pressures and temperatures</td></tr></table></td></tr>
<tr><td>User Information</td><td>The information for these fields is optional. The general details entered here provide the banner/header information that identify the reservoir in the reports and plots generated by the program</td></tr>
<tr><td>User Comments and Date Stamp</td><td>Space where a log of the updates or changes to the file can be stored. This comments box can also be used to exchange information between users. An unlimited amount of text is allowed.
Press Ctrl+Enter to start a new paragraph.
The comments box can be viewed by either dragging the scroll bar thumb or using the up and down directional arrow keys.
The Date Stamp command adds the current date and time to the User Comments Box</td></tr>
</table>

Working with the tool

Before using the Monte-Carlo analysis tool, after entering the necessary entries in the 'Options' menu, proceed to the PVT menu to enter the PVT properties of the fluid in place. Refer to Describing the PVT 70 for information on the PVT.
Next choose 'Distributions' to enter the reservoir parameters.

2.6.4 Distributions



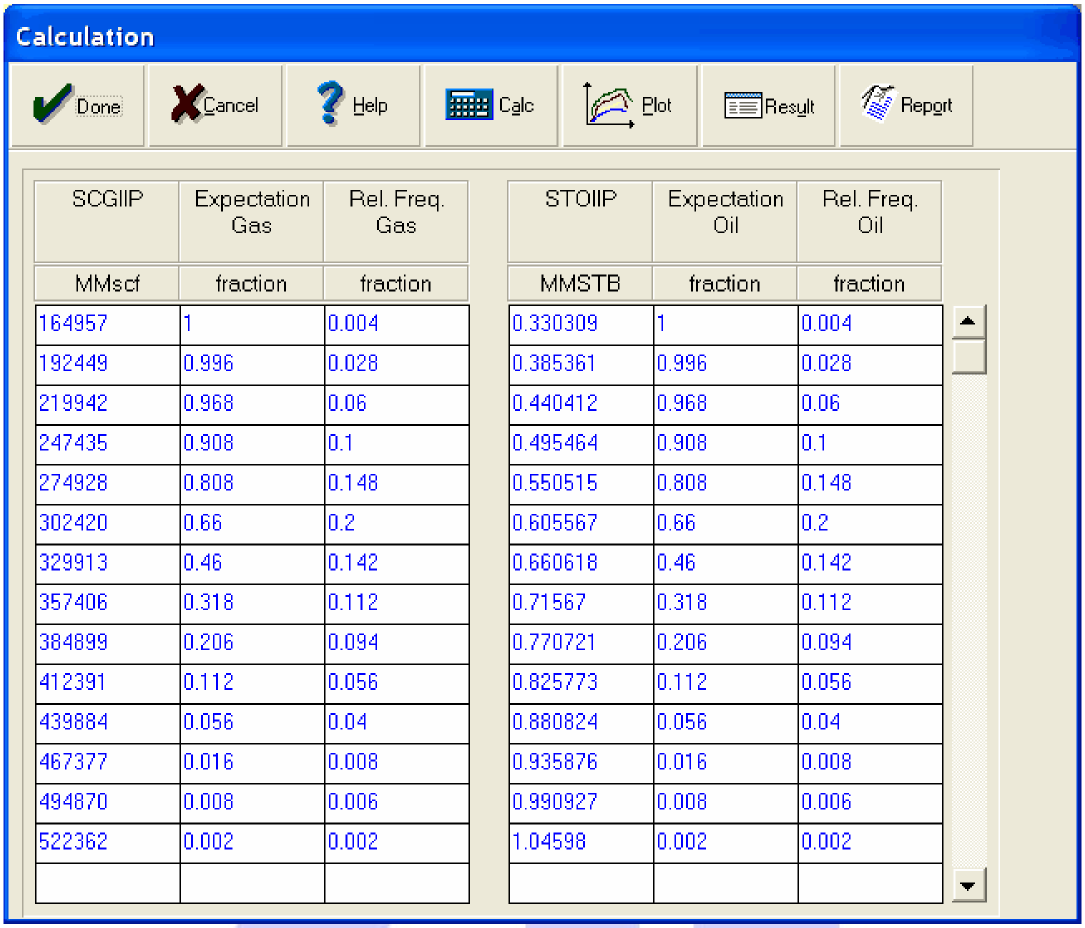
Number of Cases 500
Histogramme Steps 20
Temperature 200 deg F
Pressure 5500 psig
● Bulk Volume x N/G Ratio
○ Area x Net Thickness

	Distribution	Minimum	Maximum	Mode	Average	Standard Deviation	
Bulk Volume	Triangular	20000	50000	35000	23412	0.2	MMft3
N/G Ratio	Fixed Value	0.2	0.6				fraction
Porosity	Fixed Value	0.2					fraction
Gas Saturation	Uniform	0.6	0.9				fraction
CGR	Fixed Value	2					STB/MMscf
Oil Gravity	Fixed Value	39					API
Gas Gravity	Fixed Value	0.78					sp. gravity

Input Fields

Number of Cases	Defines the number of segments of equal probability the distribution will be divided into
Histogram Steps	Defines the number of steps that will be plotted on the histogram
Temperature	Defines the reservoir temperature
Pressure	Defines the reservoir initial pressure
Method	The pore volume can be calculated using: Bulk Volume * N/G ratio Area * Net Thickness
Distribution Type	For each reservoir parameter listed (Area Gas Gravity), select the appropriate distribution type from the list box available for each field entry, and enter the values required

When all the necessary parameters have been entered, click **Calc** to enter the calculation screen. The following dialogue box is displayed:



SCGIIP	Expectation Gas	Rel. Freq. Gas
MMscf	fraction	fraction
164957	1	0.004
192449	0.996	0.028
219942	0.968	0.06
247435	0.908	0.1
274928	0.808	0.148
302420	0.66	0.2
329913	0.46	0.142
357406	0.318	0.112
384899	0.206	0.094
412391	0.112	0.056
439884	0.056	0.04
467377	0.016	0.008
494870	0.008	0.006
522362	0.002	0.002

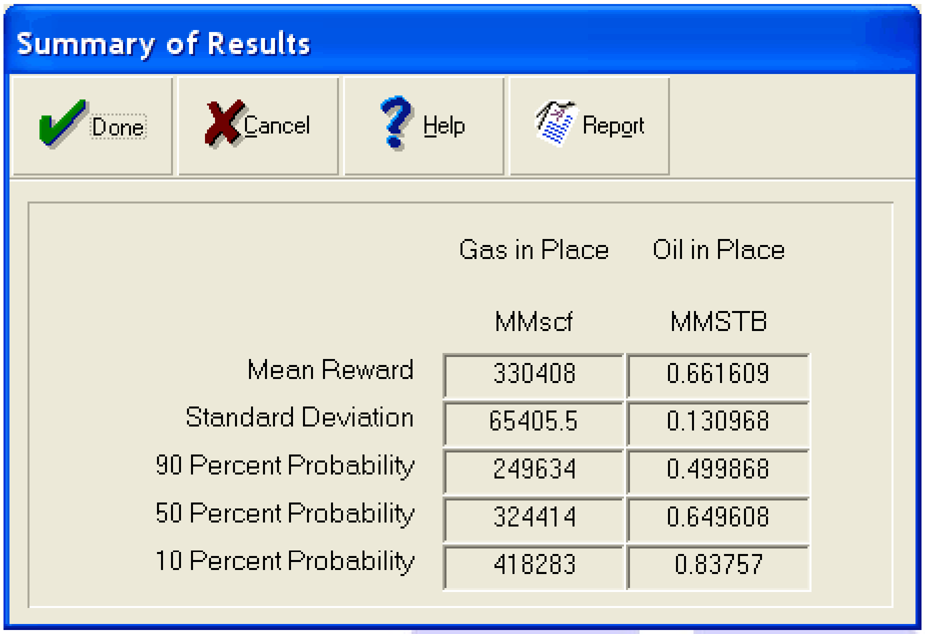
STOIIP	Expectation Oil	Rel. Freq. Oil
MMSTB	fraction	fraction
0.330309	1	0.004
0.385361	0.996	0.028
0.440412	0.968	0.06
0.495464	0.908	0.1
0.550515	0.808	0.148
0.605567	0.66	0.2
0.660618	0.46	0.142
0.71567	0.318	0.112
0.770721	0.206	0.094
0.825773	0.112	0.056
0.880824	0.056	0.04
0.935876	0.016	0.008
0.990927	0.008	0.006
1.04598	0.002	0.002

This calculation dialogue box displays the results of the previous calculation. Click the **Calc** command to start a new calculation. The new distribution results are displayed when the calculation finishes.

The expectation oil indicates the probability that the oil in place is equal to or greater than the stated value. Thus the oil in place corresponding to expectation oil of 1 is the minimum oil in place as per the data provided. Similarly, there is 50 % probability that the oil in place is equal to greater than the oil in place corresponding to expectation value of 0.5.

The relative frequency oil is the proportion or percentage of data elements falling in that particular class of values. The summation of the relative frequency oil will be equal to 1.

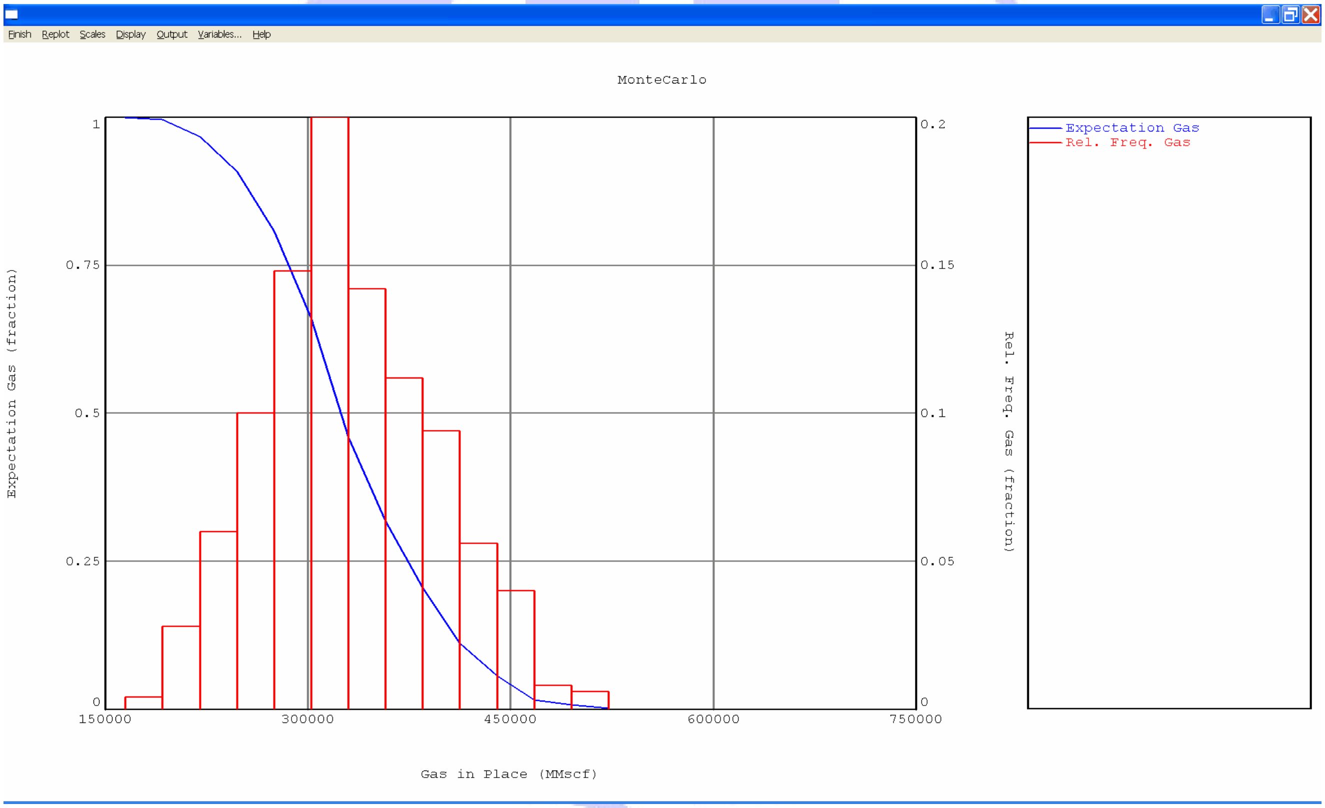
To view the results of the 10%, 50% and 90% probabilities, click the **Result** command. The following dialogue box is displayed:


Summary of Results
Done
Cancel
Help
Report

	Gas in Place MMscf	Oil in Place MMSTB
Mean Reward	330408	0.661609
Standard Deviation	65405.5	0.130968
90 Percent Probability	249634	0.499868
50 Percent Probability	324414	0.649608
10 Percent Probability	418283	0.83757

To view the calculations graphically, click the **Plot** command.

The following type of view will be observed:



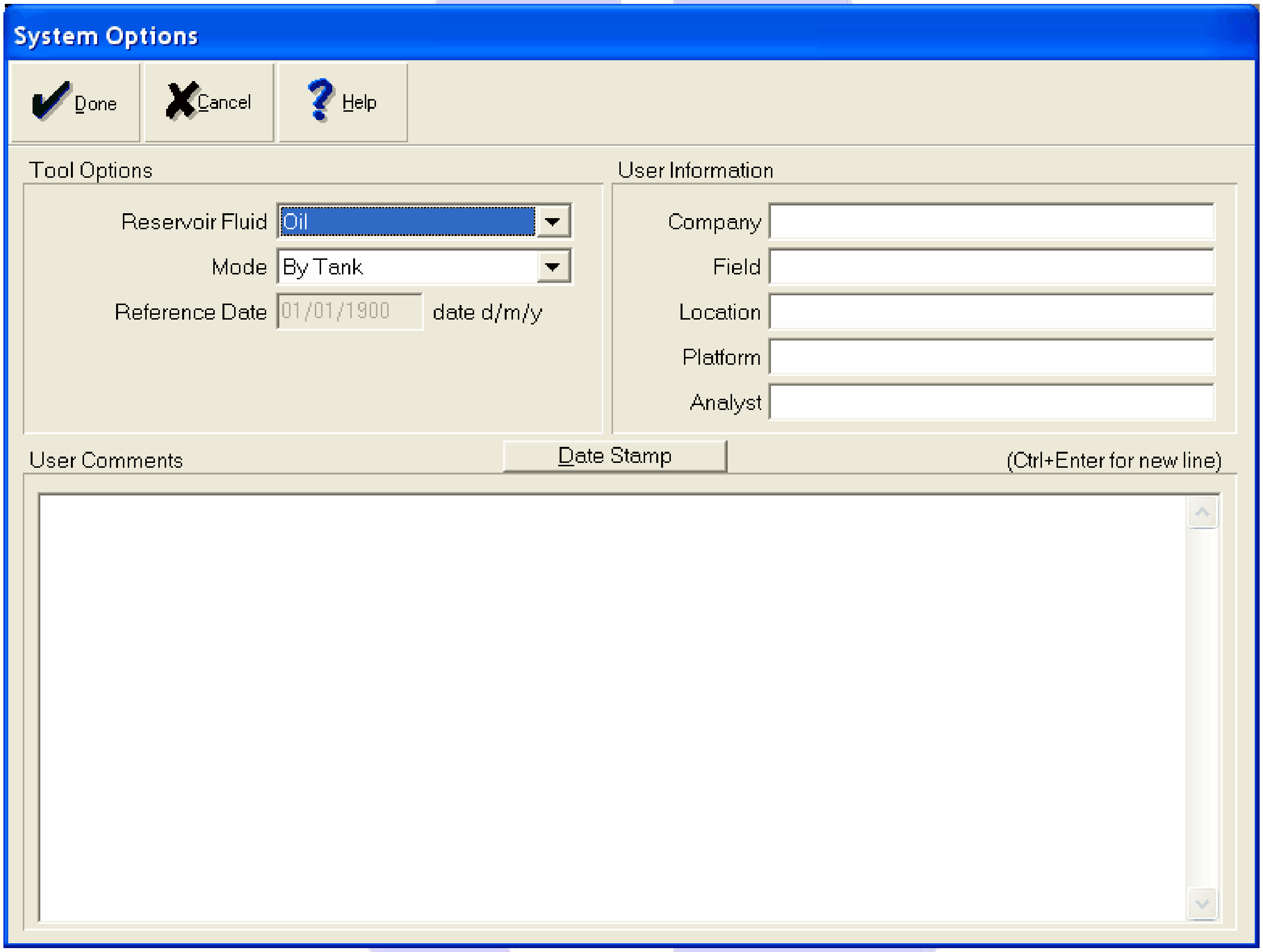
2.7 Decline Curve Analysis

2.7.1 Tool Options

The 'Decline Curve' analysis tool can be used for 'Production History Matching' and/or 'Production Prediction'. For 'Production History Matching', the program uses a non-linear regression to determine the parameters of the decline.

Having selected 'Decline Curve' as the analysis tool in the **Tool** menu, the primary fluid of the reservoir is defined in the **Options** menu.

This section describes the 'Tool Options' section of the System Options dialogue box. For information on the User Information and User Comments sections, refer to System Options 68 of this guide.


System Options
Done
Cancel
Help
Tool Options
User Information
User Comments
Date Stamp
(Ctrl+Enter for new line)

Reservoir Fluid: Oil

Mode: By Tank

Reference Date: 01/01/1900 date d/m/y

Company:

Field:

Location:

Platform:

Analyst:

Input Fields

<table>
<tr><td>Reservoir Fluid</td><td>Choose from oil, gas and retrograde condensate. However, the choice only effects the input and output units of the rates as the theory does not take any fluid properties into account
The options relating to the modelling of reservoir fluids in MBAL have been described in Describing the PVT 70.</td></tr>
<tr><td>Mode</td><td>This is the format the production history is entered. Two options are available:
<table>
<tr><td>By Tank</td><td>This option requires the production history to be entered for each tank. The tank production history can then be used for history matching</td></tr>
<tr><td>By Well</td><td>The history by well option requires the input of the production history for each well of the reservoir. The user will then be able to allocate all or some of the well production/ injection constraints to the reservoir history for each tank which can then be used in history matching</td></tr>
</table></td></tr>
<tr><td>Reference Time</td><td>The format that time data is displayed in MBAL can be of two types:
<table>
<tr><td>Date</td><td>A calendar date displayed in the format defined by Windows e.g. 23/12/2001 or 02/28/98</td></tr>
<tr><td>Time</td><td>A decimal number of days, weeks, months or years since a reference date</td></tr>
</table>
The format is selected for the time unit type in the 'Units' dialogue.
If days, weeks, months or years (rather than date format) have been selected, this field allows entering the reference date.</td></tr>
<tr><td>User Information</td><td>The information for these fields is optional. The general details entered here provide the banner/header information that identify the reservoir in the reports and plots generated by the program</td></tr>
<tr><td>User Comments and Date Stamp</td><td>Space where a log of the updates or changes to the file can be stored. This comments box can also be used to exchange information between users. An unlimited amount of text is allowed.
Press Ctrl+Enter to start a new paragraph.
The comments box can be viewed by either dragging the scroll bar thumb or using the up and down directional arrow keys.
The Date Stamp command adds the current date and time to the User Comments Box</td></tr>
</table>

Click ***Done*** to accept the selections and return to the main menu. See Options menu for information on the 'User comments' box and 'Date stamp'.

➲ Please note that the remainder of this chapter describes the features of the program using the 'Well by Well' mode. Some screens will differ slightly if the 'Reservoir' mode is used, but are usually simpler.

2.7.2 Programme Functions

This tool analyses the decline of production of a well or reservoir versus time. It uses the hyperbolic decline curves described by Fetkovich based on the equation:

$$\frac{q}{q_i} = \left(1+bi*a*\Delta t\right)^{-\frac{1}{a}}$$

where:
q is the production rate,
qi is the initial production rate,
a is the hyperbolic decline exponent,
bi is the initial decline rate,
t is the time.

By integrating equation, the cumulative production can be represented by:

for $a \neq 1$

$$P = \frac{1}{a-1}\frac{qi}{bi}\left(\left(1+bi*a*\Delta t\right)^{\left(1-\frac{1}{a}\right)} - 1\right)$$

for $a = 1$

$$P = \frac{qi}{bi} * \log\left(1+bi*\Delta t\right)$$

The program also supports production rate 'breaks' or discontinuities. These breaks can be attributed to well stimulation, change of completion, etc.

Tool Use

The Decline Curve analysis tool can be used for 'Production History Matching' and/or 'Production Prediction'. For Production History Matching, the program uses a non-linear regression to determine the parameters of the decline.

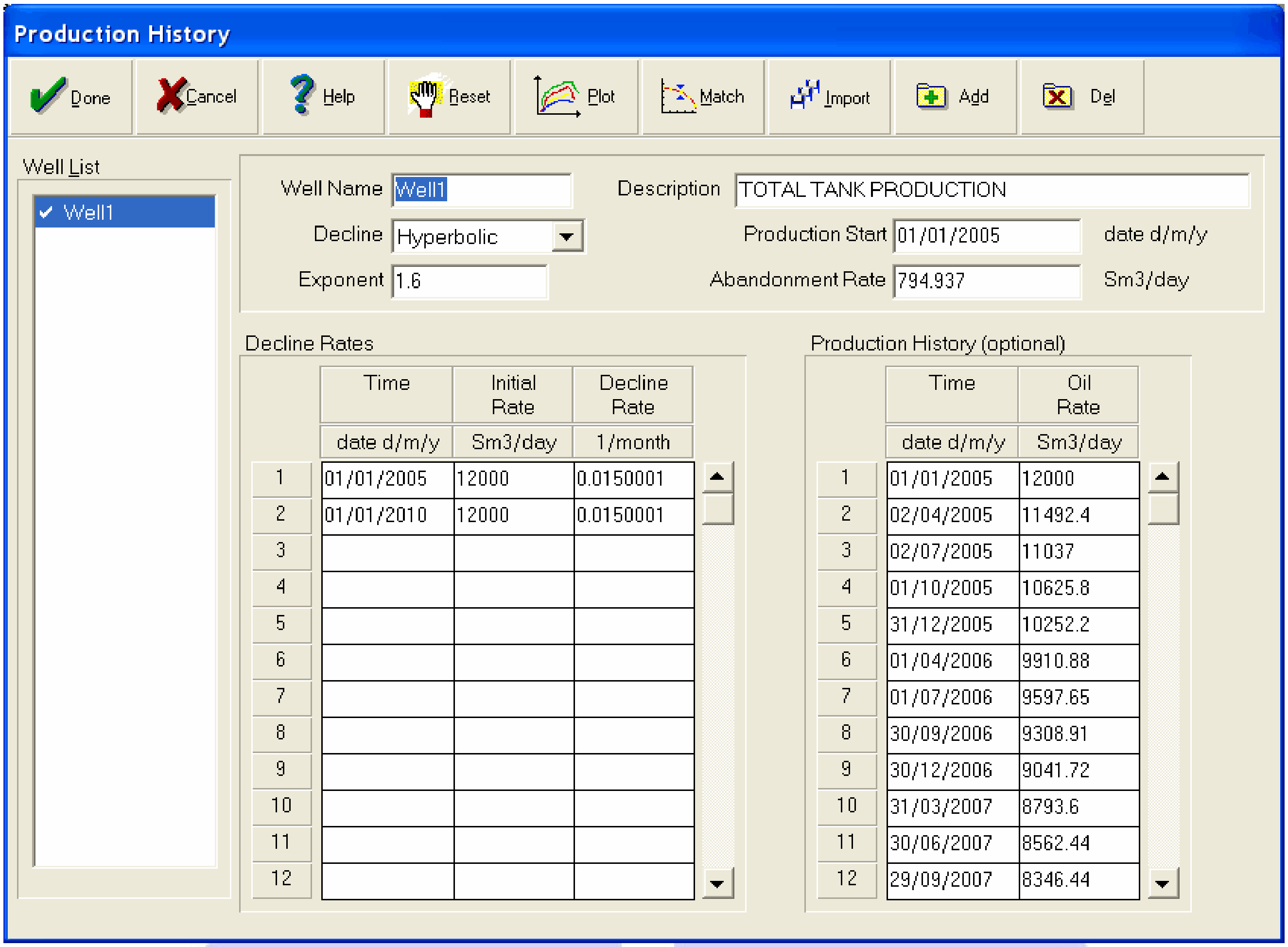
Having selected 'Decline Curve' as the analysis tool in the **Tool** menu, the primary fluid of the reservoir is defined in the **Options** menu.

Next choose Input | Production History to enter the production history.

2.7.3 Production History

This screen is used to enter the well production history, along with the time or date of the eventual production rate breaks.

The following dialogue box appears:



Well Name: Well1

Description: TOTAL TANK PRODUCTION

Decline: Hyperbolic

Production Start: 01/01/2005 date d/m/y

Exponent: 1.6

Abandonment Rate: 794.937 Sm3/day

Decline Rates

	Time date d/m/y	Initial Rate Sm3/day	Decline Rate 1/month
1	01/01/2005	12000	0.0150001
2	01/01/2010	12000	0.0150001
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

Production History (optional)

	Time date d/m/y	Oil Rate Sm3/day
1	01/01/2005	12000
2	02/04/2005	11492.4
3	02/07/2005	11037
4	01/10/2005	10625.8
5	31/12/2005	10252.2
6	01/04/2006	9910.88
7	01/07/2006	9597.65
8	30/09/2006	9308.91
9	30/12/2006	9041.72
10	31/03/2007	8793.6
11	30/06/2007	8562.44
12	29/09/2007	8346.44

Input Fields

<table>
<tr>
<td>Well List</td>
<td>
<p>A list of all of the wells created in this data set. This list box can be used to scan the well models entered, by clicking on the name of the well which is to be displayed. This list box is only displayed if the production history has been defined by the user as 'By Well' in the options dialogue.</p>
<p>The well name is usually preceded by a marker indicating the status of the well:</p>
<table>
<tr><td>✓</td><td>indicates that the well data is valid. This well can be used in the production prediction calculation</td></tr>
<tr><td>No marker and the well name appear in red</td><td>The well data is incomplete or invalid. This well cannot be used in the production prediction calculation</td></tr>
</table>
</td>
</tr>
</table>

Well Name	A string of up to 12 characters containing the well, tank or reservoir name. This name is used by the plots and reports
Decline Type	Select the type of decline curve analysis; hyperbolic, harmonic or exponential
Description	(optional) A brief description of the well, tank or reservoir
Production Start	This field is used as a date origin for plot displays and reporting purposes only. It is used to produce plots and reports with date references, when the production history is entered in days or years. When the production history is entered by date, the reports and plots can be generated in days or years
Abandonment Rate	(optional) This field is defines the minimum production rate for this well
Decline Rates	Use this table to enter a list of decline periods (initial rate + decline rate) versus time. At least one decline period rate must be entered. Several decline periods can be entered if there is a discontinuity in the decline rate of the production of the well. This can be due to a well stimulation, a change of completion, extended shut-down period, etc. Note that the exponent is the same for all the decline period. Only the initial rate and the decline rate are changing. This table can be filled in by using the 'Match' option (see Matching the Decline Curve section that follows). Records can be switched 'Off' or 'On' by depressing the buttons to the left of the column entry fields. When a record is switched 'Off', it is not taken into account in the calculations
Production History	(optional) Use this table to enter the production rate history. Records are automatically sorted in ascending order by time, or date. To view more records, use the scroll bar to the right of the columns. To delete a record, simply blank out all the fields in the corresponding row. To add or insert a new record, just enter the records at the end of the list which have already been created, and the program will automatically sort the records in ascending order. Records can be switched 'Off' or 'On' by depressing the buttons to the left of the column entry fields. When a record is switched 'Off', it is not taken into account in the calculations. The production history is used to automatically generate the exponent, initial rates and decline rates. This can be done by clicking the 'Match' button (see Matching the Decline Curve section that follows)

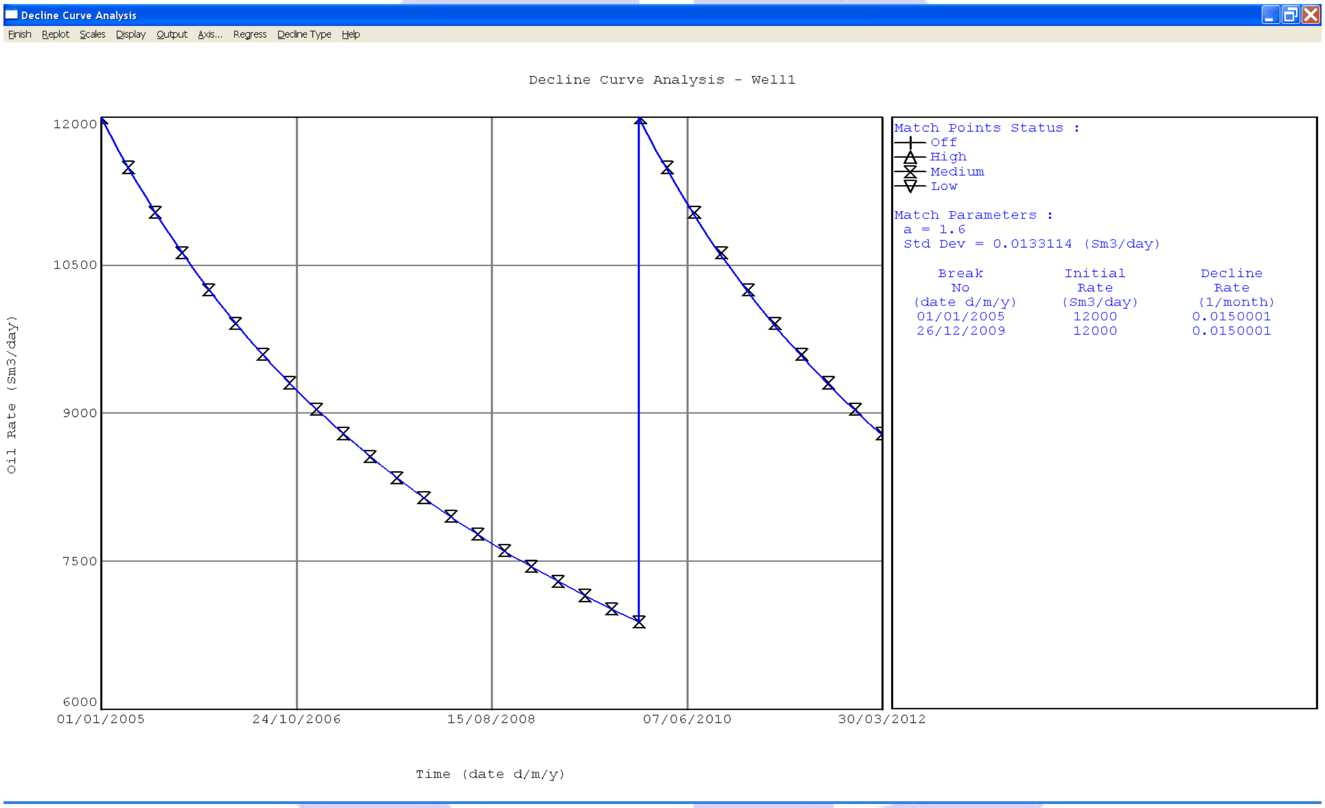
Enter the required information, and press ***Done*** to confirm the input data and exit the screen. If the quality and validity of the data are to be verified, click the **Plot** command button.

Command Buttons:

Plot	Displays the production history profile versus time.
Reset	Initialises the current tank/well data.
Match	Allows the calculation of the exponent, initial rates and decline rates from the production data.
Import	Reads a data file generated by other systems which contains production history data.
Add	Creates a new well. For By Well input only.
Del	Removes the well currently selected for the well list. The data contained in the well is lost. For By Well input only.

2.7.4 Matching the Decline Curve

To access the history matching screen, click in the ***Match*** from the production history screen, a screen plot will then be seen (as observed below):


Decline Curve Analysis
Finish
Replot
Scales
Display
Output
Axis...
Regress
Decline Type
Help
Decline Curve Analysis - Well1
Oil Rate (Sm3/day)
12000
10500
9000
7500
6000
01/01/2005
24/10/2006
15/08/2008
07/06/2010
30/03/2012
Time (date d/m/y)
Off
High
Medium
Low

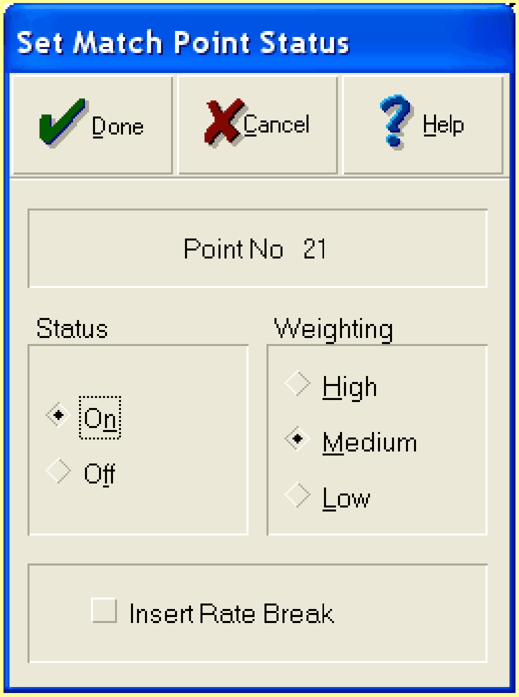
```
Match Points Status :
Match Parameters :
 a = 1.6
 Std Dev = 0.0133114 (Sm3/day)

    Break          Initial         Decline
     No              Rate            Rate
 (date d/m/y)     (Sm3/day)       (1/month)
  01/01/2005        12000         0.0150001
  26/12/2009        12000         0.0150001
```

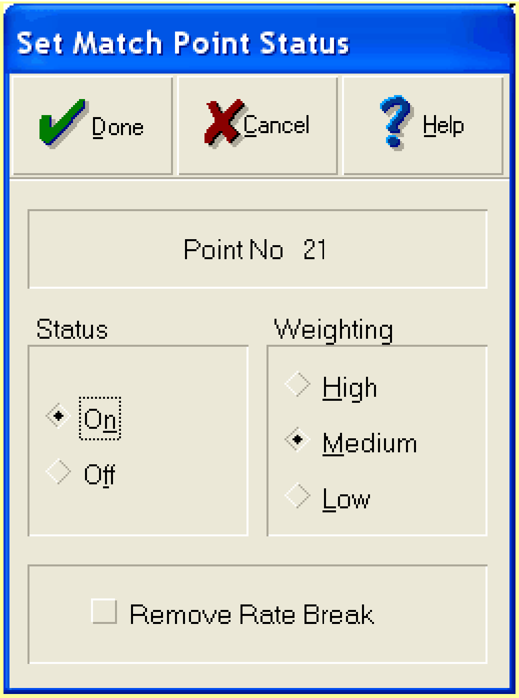
On first entry into this screen, only the matching points are displayed.

Choose **Regress** to start the non-linear regression and find the best fit. The decline curve parameters corresponding to the best fit found by the regression are displayed in the legend box the right of the plot.

Changing the weighting of history points in the regression

Each data point can be given a different weighting in the regression. Important and trustworthy data points can be set to HIGH to force the regression to go through these points. Secondary or doubtful data points can be set to LOW or switched OFF completely

Changing Single Points	Using the **LEFT** mouse button, double-click the history point to be changed.  Point No 21 Status ● On ○ Off Weighting ○ High ● Medium ○ Low ☐ Insert Rate Break The above dialogue box appears, displaying the point number selected. Choose as required, the point weighting (High / Medium / Low) and/or status (Off / On). Points that are switched off will not be accounted for during the regression. Checking the *Insert Rate Break* option creates a new entry in the decline rate table i.e. indicates to the program the occurrence of a discontinuity in the rate decline. If a rate break has already been inserted at that point, the following screen is displayed:


Set Match Point Status
Done
Cancel
Help

Point No 21

Status
● On
○ Off

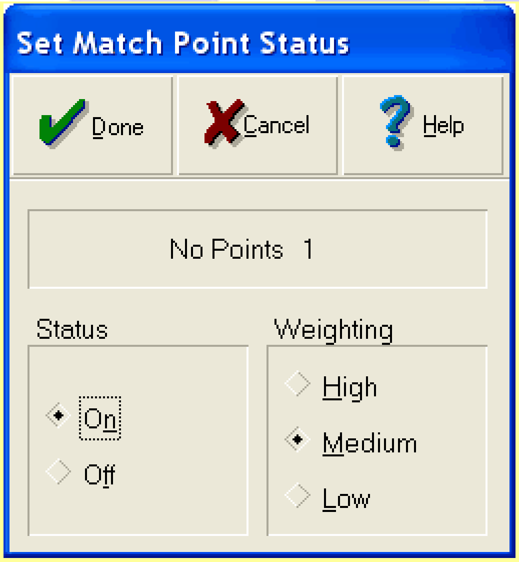
Weighting
○ High
● Medium
○ Low

☐ Remove Rate Break

Checking the *Remove Rate Break* removes the corresponding entry from the decline rate table.

Click ***Done*** to confirm the changes

Changing Multiple Points


Set Match Point Status
Done
Cancel
Help

No Points 1

Status
● On
○ Off

Weighting
○ High
● Medium
○ Low

Using the **RIGHT** mouse button and dragging the mouse, draw a dotted rectangle over the points requiring modification. (This click and drag operation is identical to the operation used to re-size plot displays, but uses the right mouse button.) When the mouse button has been released, a dialogue box similar to the above will appear displaying the number of points selected.

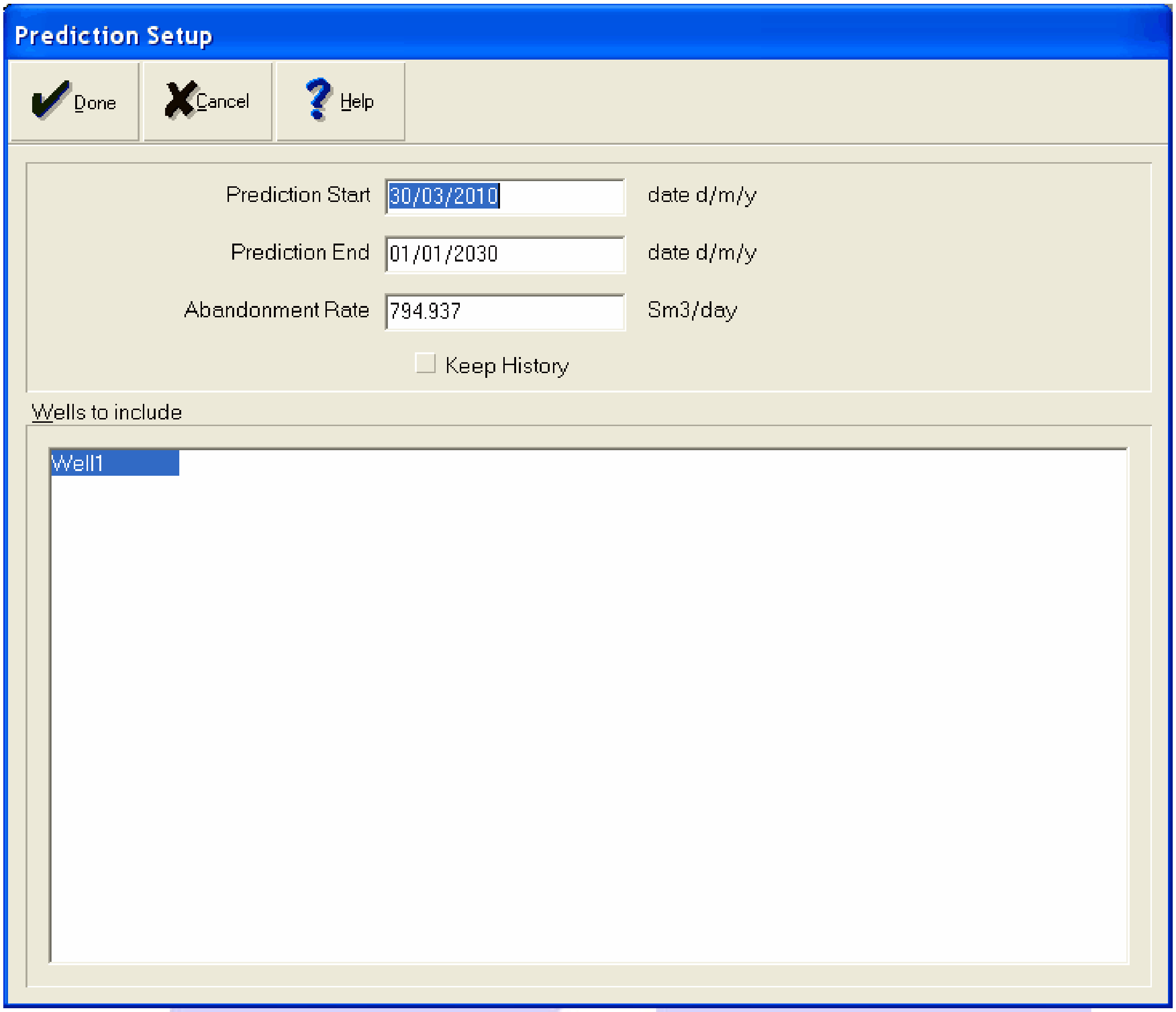
	All of the history points included in the 'drawn' box will be affected by the selections made by the user. Choose the points' weighting (High / Medium / Low) and/or status (Off / On) as desired. Click ***Done*** to confirm the changes. If the user does not have a right mouse button, the button selection can still be performed by using the left mouse button and holding the shift key down while clicking and dragging ➲ Do not forget to choose **Regress** again to start a new regression wit values.

Menu Commands

Axis	Allows different types of scales for the X and Y axes to be selected. It is also possible to display the estimated cumulative production based on the last regression parameters.
Prior	Plots the production data of the previous well in the well list of the production screen above.
Next	Plots the production data of the next well in the well list of the production screen above.
Regress	Starts the non-linear regression and finds the best fit. The Decline Curve parameters corresponding to the best fit found by the regression are displayed in the legend box the right of the plot.
Decline Type	Select the type of decline curve analysis; hyperbolic, harmonic or exponential.

2.7.5 Prediction Set-up

This option is used to enter the production prediction parameters to access the prediction parameters screen, choose **Production Prediction|Prediction Set-up**. The following dialogue box appears:



Prediction Start 30/03/2010 date d/m/y

Prediction End 01/01/2030 date d/m/y

Abandonment Rate 794.937 Sm3/day

☐ Keep History

Wells to include

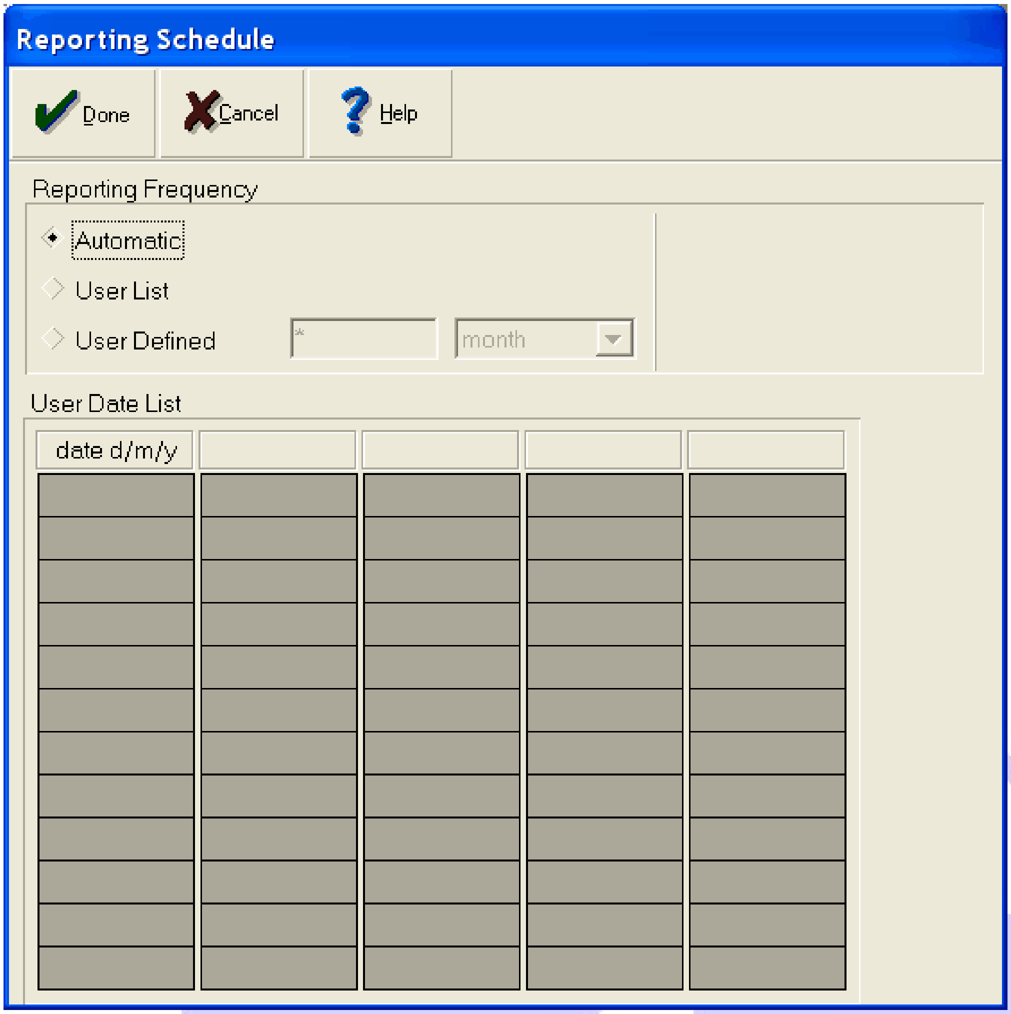
Well1

Input Fields

Start of Prediction	This field defines the start date of the prediction
Prediction end	This parameter defines when the program will stop the prediction
Abandonment rate	(optional) This field defines the minimum production rate for the prediction
Wells to include	(only displayed if 'By Well' selected in the options dialogue) Select the wells to be included in the prediction. Only valid wells are presented in this list

2.7.6 Reporting Schedule

The reporting schedule allows the definition of; type of prediction, reporting frequency and the start and end date of the prediction to be carried out.


Reporting Schedule
Done
Cancel
Help
Reporting Frequency
Automatic
User List
User Defined
month
User Date List
date d/m/y

Reporting Frequency: ● Automatic ○ User List ○ User Defined

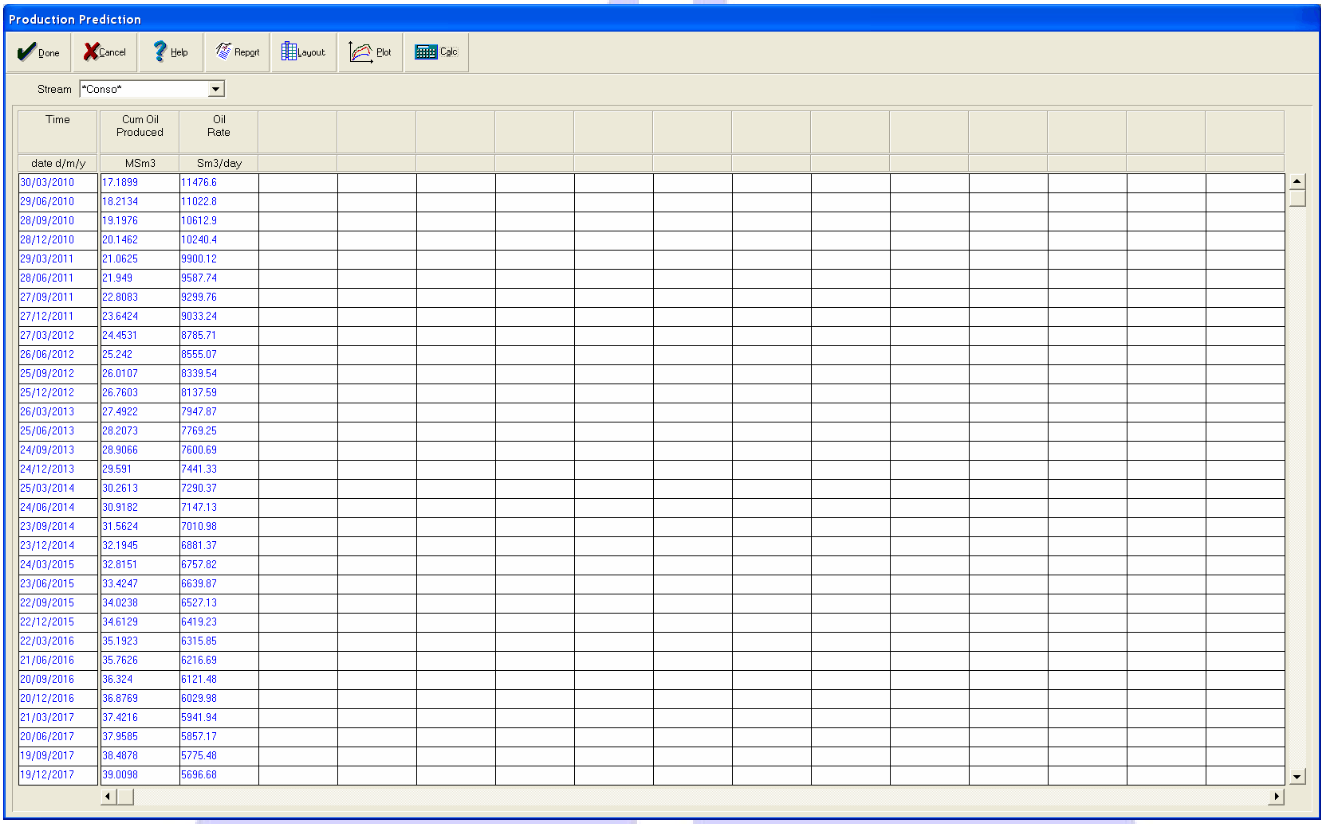
Input Fields

Reporting Frequency	This parameter defines when the prediction result is displayed	
	Automatic	The programme displays a calculation every 90 days
	User List	A list of dates can be set in the table provided. Any r can be entered and in any order - **MBAL** will sort the correct order
	User Defined	The user can defined any date increment in days, we years in the adjacent fields

Enter the required information, and press ***Done*** to confirm the input data and exit the screen.

2.7.7 Running a Production Prediction

To run a prediction, **Production Prediction|Calculation** should be selected to be able to view the following dialogue box:



Stream *Conso*

Time	Cum Oil Produced	Oil Rate
date d/m/y	MSm3	Sm3/day
30/03/2010	17.1899	11476.6
29/06/2010	18.2134	11022.8
28/09/2010	19.1976	10612.9
28/12/2010	20.1462	10240.4
29/03/2011	21.0625	9900.12
28/06/2011	21.949	9587.74
27/09/2011	22.8083	9299.76
27/12/2011	23.6424	9033.24
27/03/2012	24.4531	8785.71
26/06/2012	25.242	8555.07
25/09/2012	26.0107	8339.54
25/12/2012	26.7603	8137.59
26/03/2013	27.4922	7947.87
25/06/2013	28.2073	7769.25
24/09/2013	28.9066	7600.69
24/12/2013	29.591	7441.33
25/03/2014	30.2613	7290.37
24/06/2014	30.9182	7147.13
23/09/2014	31.5624	7010.98
23/12/2014	32.1945	6881.37
24/03/2015	32.8151	6757.82
23/06/2015	33.4247	6639.87
22/09/2015	34.0238	6527.13
22/12/2015	34.6129	6419.23
22/03/2016	35.1923	6315.85
21/06/2016	35.7626	6216.69
20/09/2016	36.324	6121.48
20/12/2016	36.8769	6029.98
21/03/2017	37.4216	5941.94
20/06/2017	37.9585	5857.17
19/09/2017	38.4878	5775.48
19/12/2017	39.0098	5696.68

This screen shows the results of the last prediction. The scroll bars to the bottom and right of the dialogue box allow the user to browse through the calculations of the last prediction run.

To start a new prediction, click **Calc**. To abort the calculations at any stage, press the **Abort** command button.

The **Layout** button allows the specific variables of interest to the user to be the only ones to be viewed or reported.

Plotting a Production Prediction

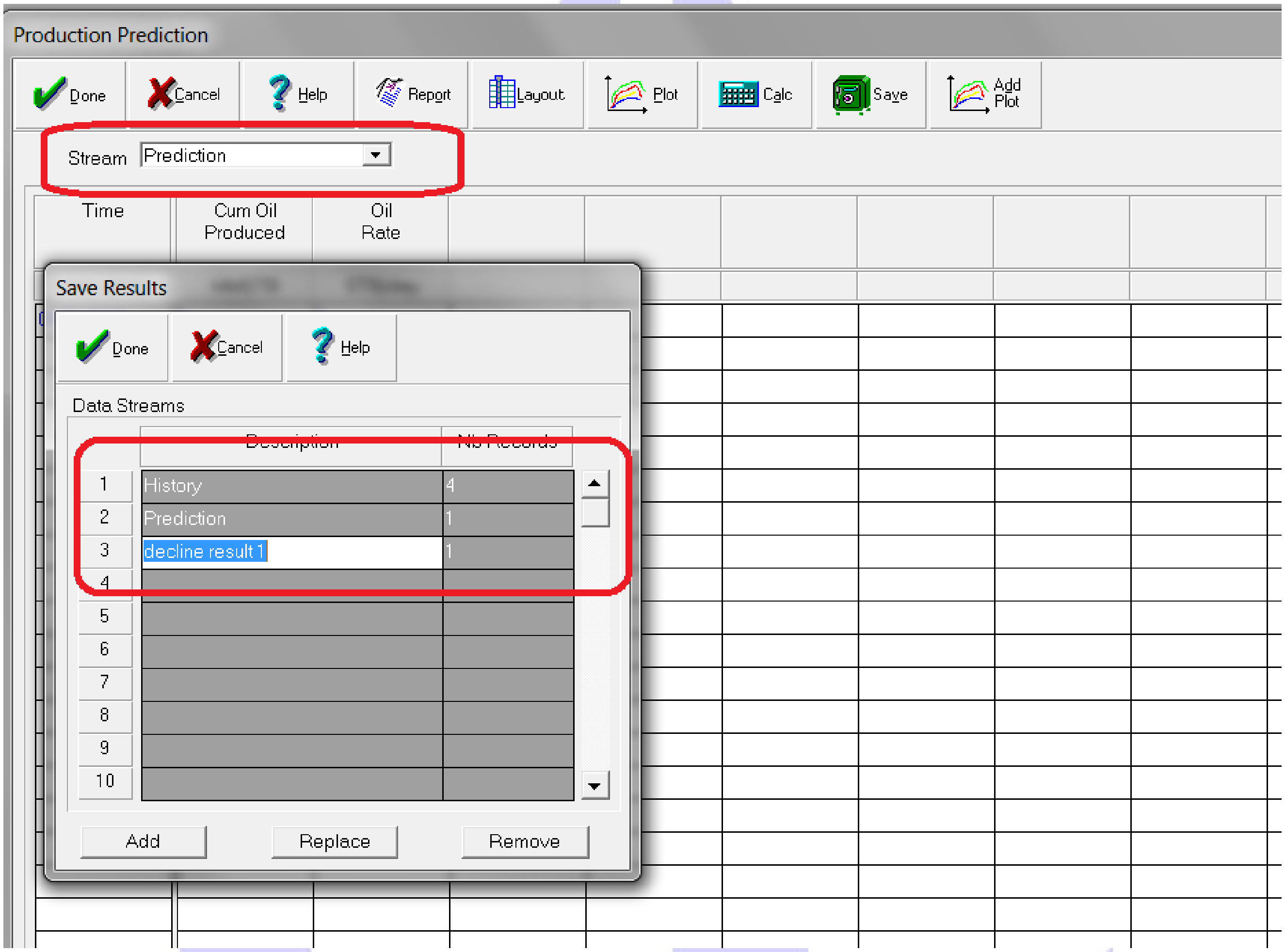
To plot the results of a prediction run, choose **Production Prediction|Plot**. This plot allows the user to select the variables on display.

2.7.8 Storing stream data

New in IPM8.0

The historical data can now be stored (a sub folder in the streams drop down menu exists to view this), and multiple predictions can also be stored.

This allows a comparison of different decline rates to be compared (with the continuity of being able to see the historical values)


Production Prediction
Done
Cancel
Help
Report
Layout
Plot
Calc
Save
Add Plot
Time
Cum Oil Produced
Oil Rate
Save Results
Done
Cancel
Help
Data Streams
Add
Replace
Remove

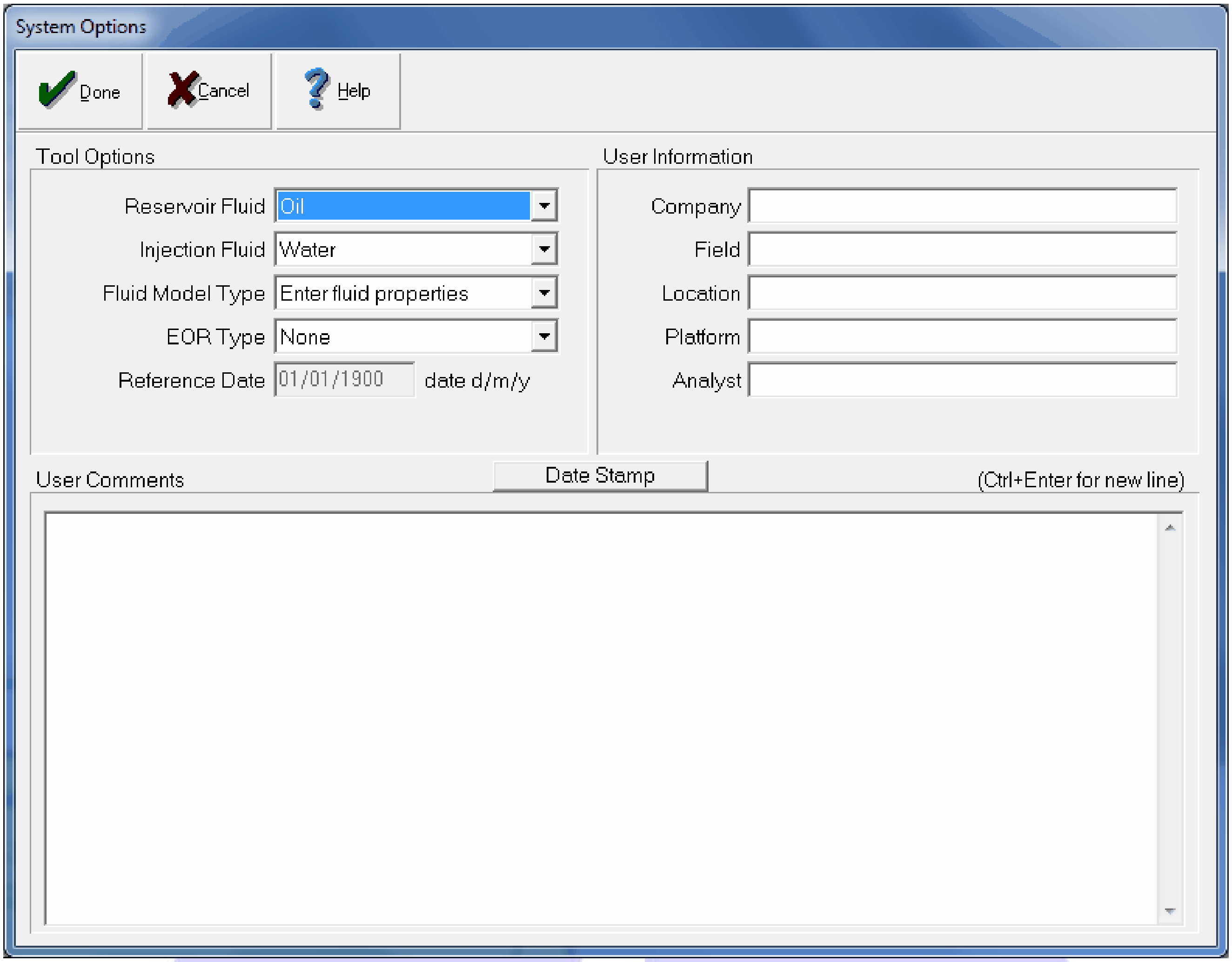
Stream: Prediction

	Description	Nb Records
1	History	4
2	Prediction	1
3	decline result 1	1
4		
5		
6		
7		
8		
9		
10		

2.8 1D Model

2.8.1 1D model options

If the 1D Model was selected the analysis tool, use this dialogue box to specify the reservoir fluid:


System Options
Done
Cancel
Help
Tool Options
User Information
Company
Field
Location
Platform
Analyst
User Comments
Date Stamp
(Ctrl+Enter for new line)

Reservoir Fluid: Oil
Injection Fluid: Water
Fluid Model Type: Enter fluid properties
EOR Type: None
Reference Date: 01/01/1900 date d/m/y

Input Fields

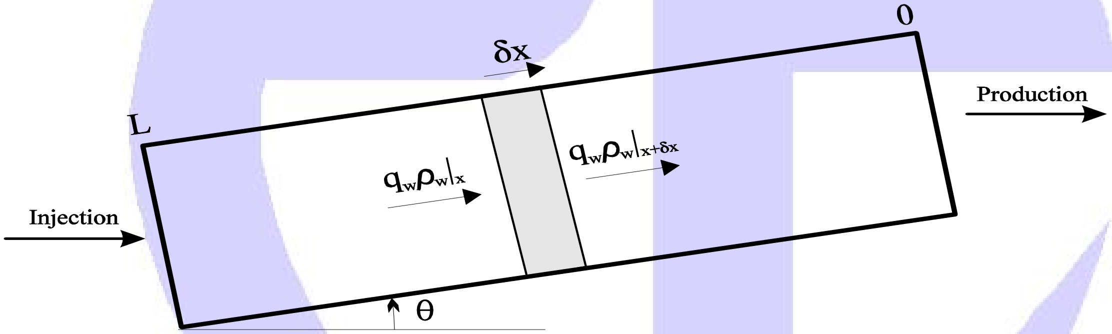
<table>
<tr><td>Reservoir Fluid</td><td>Oil type of fluid can be modeled in this tool
The options relating to the modelling of reservoir fluids in MBAL have been described in Describing the PVT 70.</td></tr>
<tr><td>Injection fluid</td><td>Injection fluid can be water or gas.</td></tr>
<tr><td>Fluid model type</td><td>Fluid properties can be directly entered by user or defined using a BO PVT model.</td></tr>
<tr><td>EOR Type</td><td>1D EOR studies : select Surfactant/Polymer flood or Hot water flood, or CO2 flood.</td></tr>
<tr><td>Reference date</td><td>The format that time data is displayed in MBAL can be of two types:
<table>
<tr><td>Date</td><td>A calendar date displayed in the format defined by Windows e. g. 23/12/2001 or 02/28/98</td></tr>
<tr><td>Time</td><td>A decimal number of days, weeks, months or years since a</td></tr>
</table></td></tr>
</table>

	reference date The format is selected for the time unit type in the units dialogue. If days, weeks, months or years (rather than date format) have been selected, this field allows entering the reference date.
User Information	The information for these fields is optional. The general details entered here provide the banner/header information that identify the reservoir in the reports and plots generated by the program
User Comments and Date Stamp	Space where a log of the updates or changes to the file can be stored. This comments box can also be used to exchange information between users. An unlimited amount of text is allowed. Press **Ctrl+Enter** to start a new paragraph. The comments box can be viewed by either dragging the scroll bar thumb or using the up and down directional arrow keys. The **Date Stamp** command adds the current date and time to the User Comments Box

Click ***Done*** to accept the selections and return to the main menu. For information on the User Comments box and Date Stamp see Options menu.

2.8.2 Technical description

This tool allows the study of the displacement of oil by water or gas, using the fractional flow and Buckley-Leverett equations. The model does not presuppose any displacement theory.



The model assumes the following:

- The reservoir is a rectangular box, with an injector well at one end and a producer at the other.

- The production and injection wells are considered to be perforated across the entire formation thickness.
- The injection rate is constant.
- The fluids are immiscible.
- The displacement is considered as incompressible hence total injected fluid = total produced fluid.
- The saturation distribution is uniform across the width of the reservoir.
- Linear flow lines are assumed, even in the vicinity of the wells.
- Capillary pressures are neglected.

2.8.3 Basic ID Model

2.8.3.1 Technical Background

Basic 1D Model

This section summarises the basic 1D model (i.e. before looking at the new flood methods).

As the name suggests the 1D Model is a simple 1D Reservoir simulator that allows generation of pseudo relative permeability curves that can represent a reservoir’s behaviour.

The reservoir is a rectangular box, with an injector well at one end and a producer at the other. The box is divided into cells for which average water/gas and oil saturations are monitored. A time step is computed based on the injection rate and the overall size of the reservoir, so as not to produce brusque changes in the cells' saturations. At each time step, the program calculates the production from cell to cell. The calculation is performed from the producer well to the injector.

At each time step and for each cell, the program calculates:

- The water/gas and oil relative permeabilities based on the cell saturations.
- The fractional flow of each fluid based on their relative permeabilities.
- The cell productions into the next cell based on the fractional flows.
- The new cell saturations from the productions.

In particular:-

- Simple 1D gridded simulator with single microscopic rel perm
- Water/gas is injected at one end and produced at the other end.

- The fluid is assumed incompressible. This means injected total fluid = produced total fluid
- We track saturations along the reservoir as we inject water.
- For Mw << Mo we expect piston like injection so breakthru will be at 100% water cut.
- If Mw >> Mo then breakthrough may happen earlier but be more gradual – poorer sweep efficiency
- Reports Fw vs reservoir saturation
- Models gravity effects for deviated reservoirs

The reservoir is split into equal sized vertical slices called cells. We track the Sw in each cell. At each time step we use the Sw and microscopic rel perm to calculate how much of the water/oil moves into the next cell. The Fw at the producing end of the reservoir can be seen to follow a simple Buckley-Levertt calculation.

2.8.3.1.1 Flow equations

In the case of displacement of oil by water, the one dimensional equations for simultaneous flow of oil and water can be expressed as:

$$q_o = -\frac{k\,k_{ro}\,A}{\mu_o}\left(\frac{\delta P_o}{\delta x} + \frac{\rho_o\,g\sin\theta}{1.0133\,x\,10^6}\right)$$

and

$$q_w = -\frac{k\,k_{rw}\,A}{\mu_w}\left(\frac{\delta P_w}{\delta x} + \frac{\rho_w\,g\sin\theta}{1.0133\,x\,10^6}\right)$$

where:

q = rate
ρ = density
k = permeability
A = cross section area
μ = viscosity
P = pressure
g = acceleration of gravity.

2.8.3.1.2 Fractional Flow

The Fractional Flow can then be expressed as:

$$f_w = \frac{q_w}{q_w + q_o} = \frac{1 + \frac{k\,k_{ro}\,A}{q_t\,\mu_o}\left(\frac{\delta P_c}{\delta x} - \frac{\Delta\rho\,g\,\sin\theta}{1.0133 \text{ x } 10^6}\right)}{1 + \frac{\mu_w\,k_{ro}}{k_{rw}\,\mu_o}}$$

which, neglecting the capillary pressure gradient with respect to x, gives:

$$f_w = \frac{1 - \frac{k\,k_{ro}\,A}{q_t\,\mu_o}\left(\frac{\Delta\rho\,g\,\sin\theta}{1.0133 \text{ x } 10^6}\right)}{1 + \frac{\mu_w\,k_{ro}}{k_{rw}\,\mu_o}}$$

.

For a displacement in a horizontal reservoir the equation is reduced to

$$f_w = \frac{1}{1 + \frac{\mu_w}{k_{rw}} \times \frac{k_{ro}}{\mu_o}} = \frac{M}{1 + M}$$

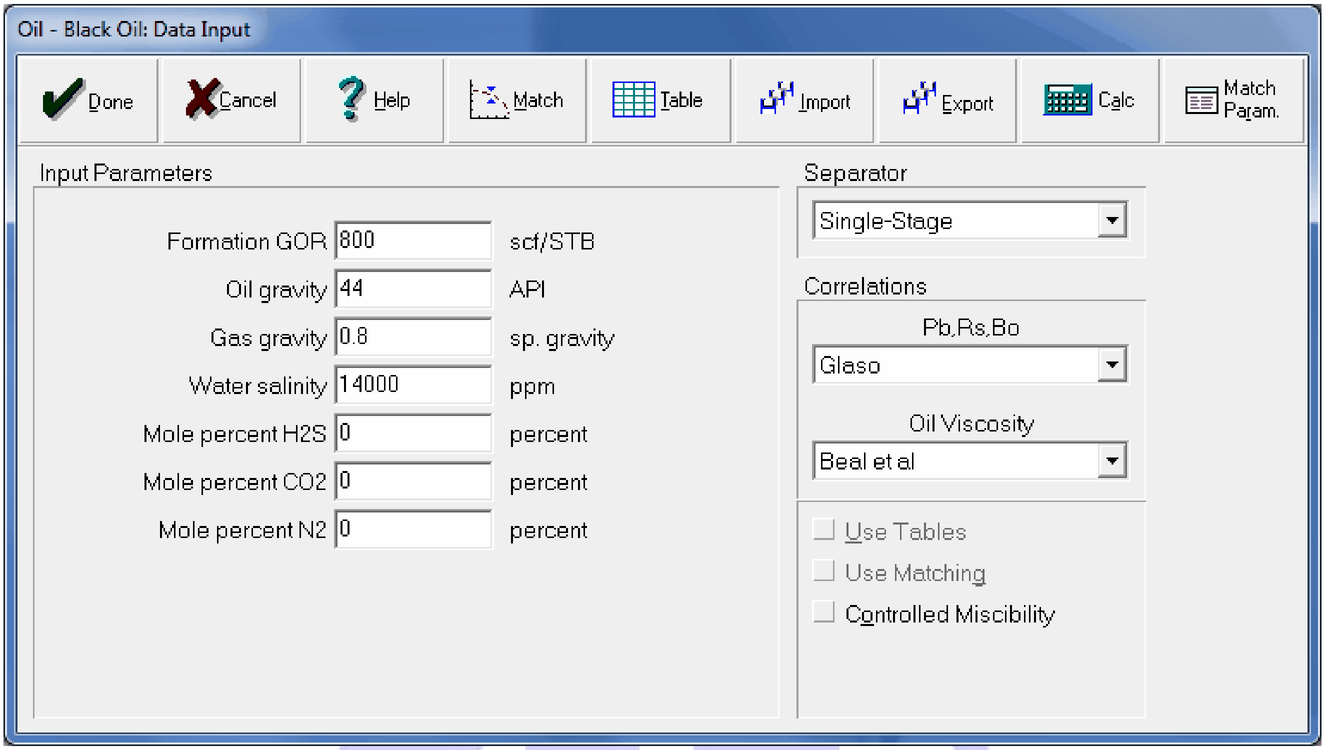
with the end point mobility factor defined as

$$M = \frac{\mu_o}{k_{ro}} \times \frac{k_{rw}}{\mu_w}.$$

2.8.3.2 Reservoir and Fluids Properties

The user has the option to define the fluid properties using a PVT model or by entering the fluid properties directly.

If the fluid properties are to be defined by a PVT model, the following screen similar to PVT description for material balance appears


Oil - Black Oil: Data Input
Done
Cancel
Help
Match
Table
Import
Export
Calc
Match Param.

Input Parameters

Formation GOR	800	scf/STB
Oil gravity	44	API
Gas gravity	0.8	sp. gravity
Water salinity	14000	ppm
Mole percent H2S	0	percent
Mole percent CO2	0	percent
Mole percent N2	0	percent

Separator: Single-Stage

Correlations

Pb,Rs,Bo: Glaso

Oil Viscosity: Beal et al

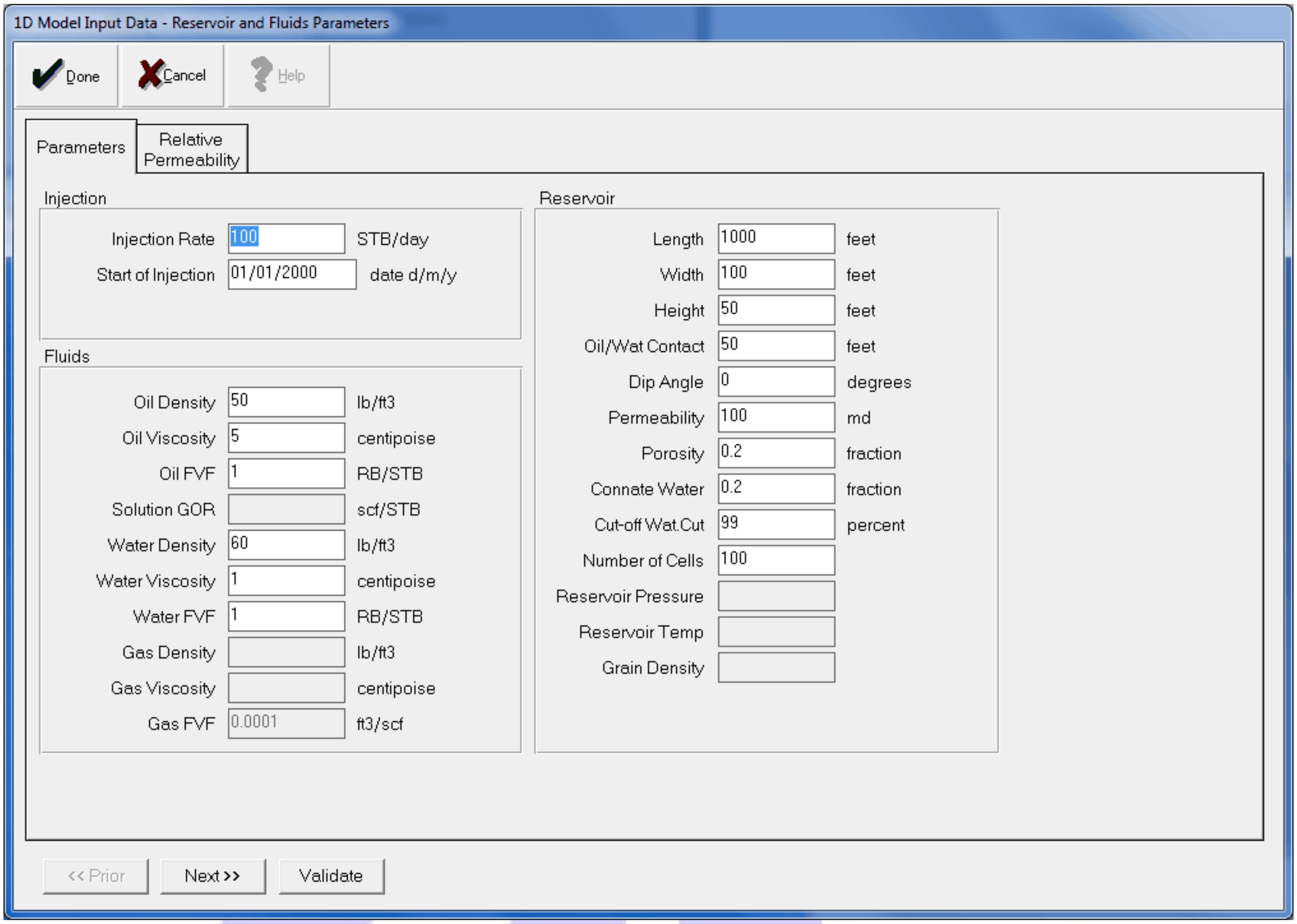
☐ Use Tables

☐ Use Matching

☐ Controlled Miscibility

To access the reservoir, injection and fluids properties (if directly entered) dialogue box, choose **Input - Reservoir Parameters** or press **ALT - R**. A screen similar to the following appears.

PE


1D Model Input Data - Reservoir and Fluids Parameters
Done
Cancel
Help
Parameters
Relative Permeability
<< Prior
Next >>
Validate

Injection

Injection Rate 100 STB/day

Start of Injection 01/01/2000 date d/m/y

Fluids

Oil Density 50 lb/ft3

Oil Viscosity 5 centipoise

Oil FVF 1 RB/STB

Solution GOR scf/STB

Water Density 60 lb/ft3

Water Viscosity 1 centipoise

Water FVF 1 RB/STB

Gas Density lb/ft3

Gas Viscosity centipoise

Gas FVF 0.0001 ft3/scf

Reservoir

Length 1000 feet

Width 100 feet

Height 50 feet

Oil/Wat Contact 50 feet

Dip Angle 0 degrees

Permeability 100 md

Porosity 0.2 fraction

Connate Water 0.2 fraction

Cut-off Wat.Cut 99 percent

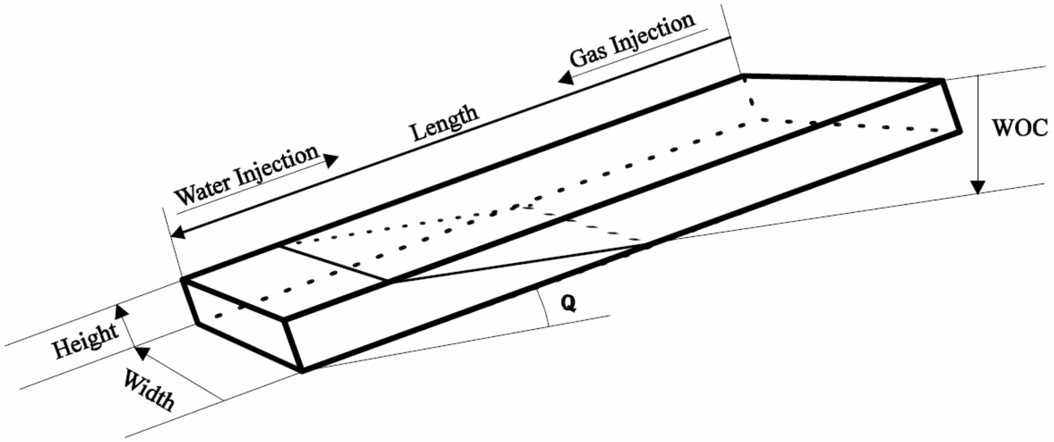
Number of Cells 100

Reservoir Pressure

Reservoir Temp

Grain Density

Input Fields


Gas Injection
Length
Water Injection
WOC
Q
Height
Width

Injection Rate	Defines the injection rate of the injection fluid
Start of Injection	Used as the origin of the date system

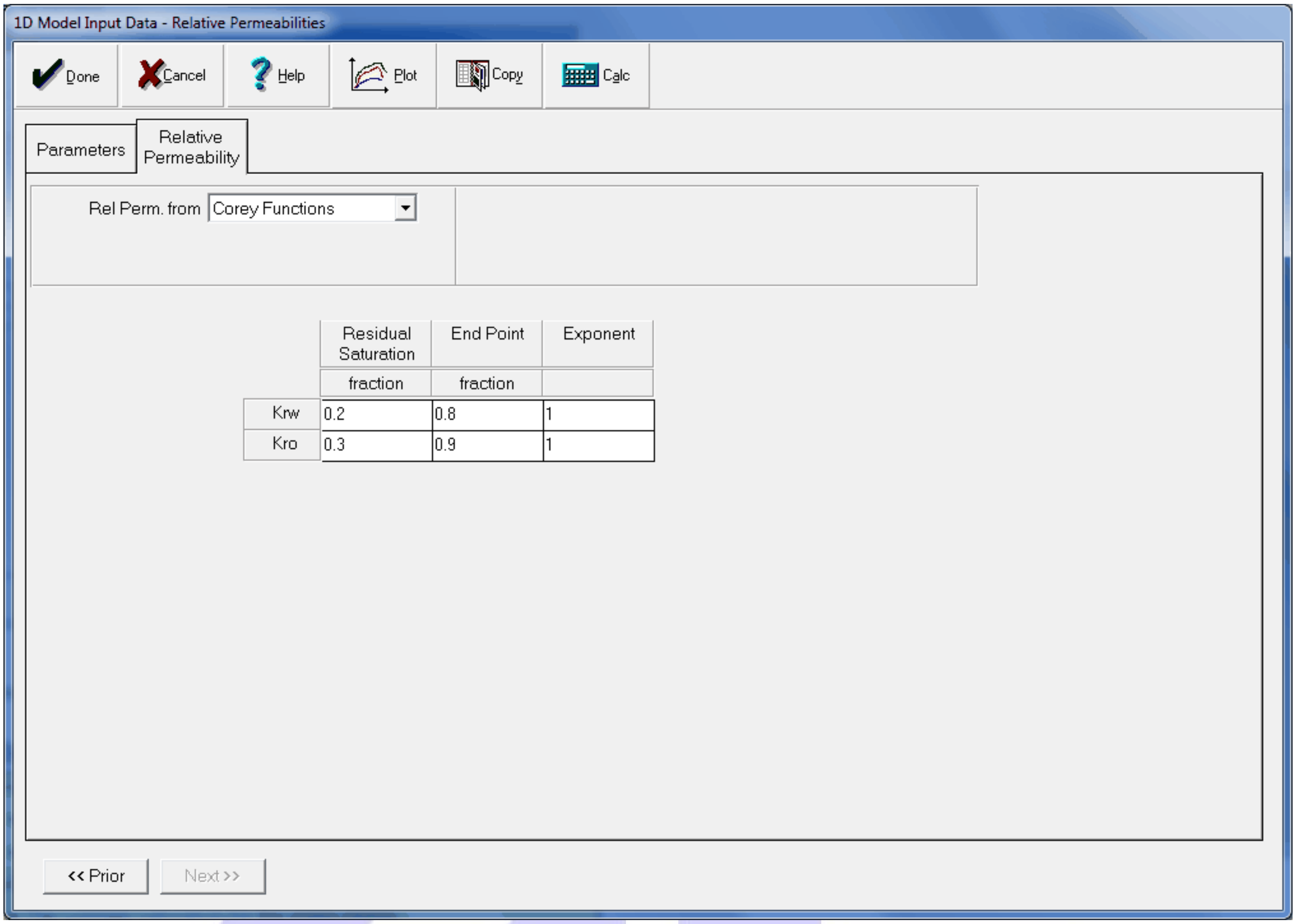
Oil Density	Density of the oil at reservoir conditions
Oil Viscosity	Viscosity of the oil at reservoir conditions
Oil FVF	Oil Formation Volume Factor at reservoir conditions
Solution GOR	For gas injection only. Used to calculate the total gas production (free + solution)
Water/Gas Density	Density of the injected fluid at reservoir conditions
Water/Gas Viscosity	Viscosity of the injected fluid at reservoir conditions
Water/Gas FVF	Injected fluid Formation Volume Factor at reservoir conditions
Reservoir Length	This refers to the length of the layer
Reservoir Width	Average width of the layer
Reservoir Height	This is the net height of the reservoir
Oil/Water or Gas/Oil Contact	The vertical distance from the top of the reservoir at the producing end to the fluid interface. When the injection fluid is gas, the gas oil contact point is also considered below the top of reservoir. A negative value can be input to represent gas oil contact above the top of reservoir
Dip Angle	Angle between the horizontal and the reservoir dip
Permeability	The average absolute permeability of the reservoir
Porosity	The average reservoir porosity
Cut-off Water Cut or GOR	Value of the Water Cut (for water injection) or GOR (for gas injection) at which the program will end the simulation run
Number of cells	Define the number of cells the block will be divided into for the simulation run (maximum 500). Choose a higher value if the injected volume is important

Enter the correct information appropriate boxes. Click ***Done*** to accept and return to the main menu.

2.8.3.3 Relative Permeability

To access the relative permeabilities dialogue box, choose **Input - Relative Permeabilities** or press **ALT - P**.

The following screen will then be observed:


1D Model Input Data - Relative Permeabilities
Done
Cancel
Help
Plot
Copy
Calc
Parameters
Relative Permeability
<< Prior
Next >>

Rel Perm. from: Corey Functions

	Residual Saturation	End Point	Exponent
	fraction	fraction	
Krw	0.2	0.8	1
Kro	0.3	0.9	1

➲ *See Corey Relative Permeability Equations in Appendix B* 483

Input Fields when Injected Fluid is WATER

Rel Perm From	Select whether the relative permeability's are to come from: • Corey Functions, or • User Defined input tables
Residual Saturations	Defines respectively: • The connate saturation for the water phase, • The residual saturation of the oil phase for water flooding, These saturations are used to calculate the amount of oil 'by-passed' during a water flooding
End Points	Defines the relative permeability at its maximum saturation for each phase. For example for the oil, it corresponds to its relative

	permeability at So = (1 - Swc)
Exponent / Corey Exponents	Defines the shape of relative permeability curve between the residual saturation and maximum saturation for each phase. See Relative Permeability Equations by Corey Exponent in Appendix B 483

Command Buttons

Reset	Initialises the relative permeability curve
Plot	Displays the relative permeability tables in a graph.
Copy	Copy a relative permeability curve from elsewhere in the system.

Click ***Done*** to exit and return to the main menu screen, or ***Cancel*** to quit the screen.

Input Fields when Injected Fluid is GAS

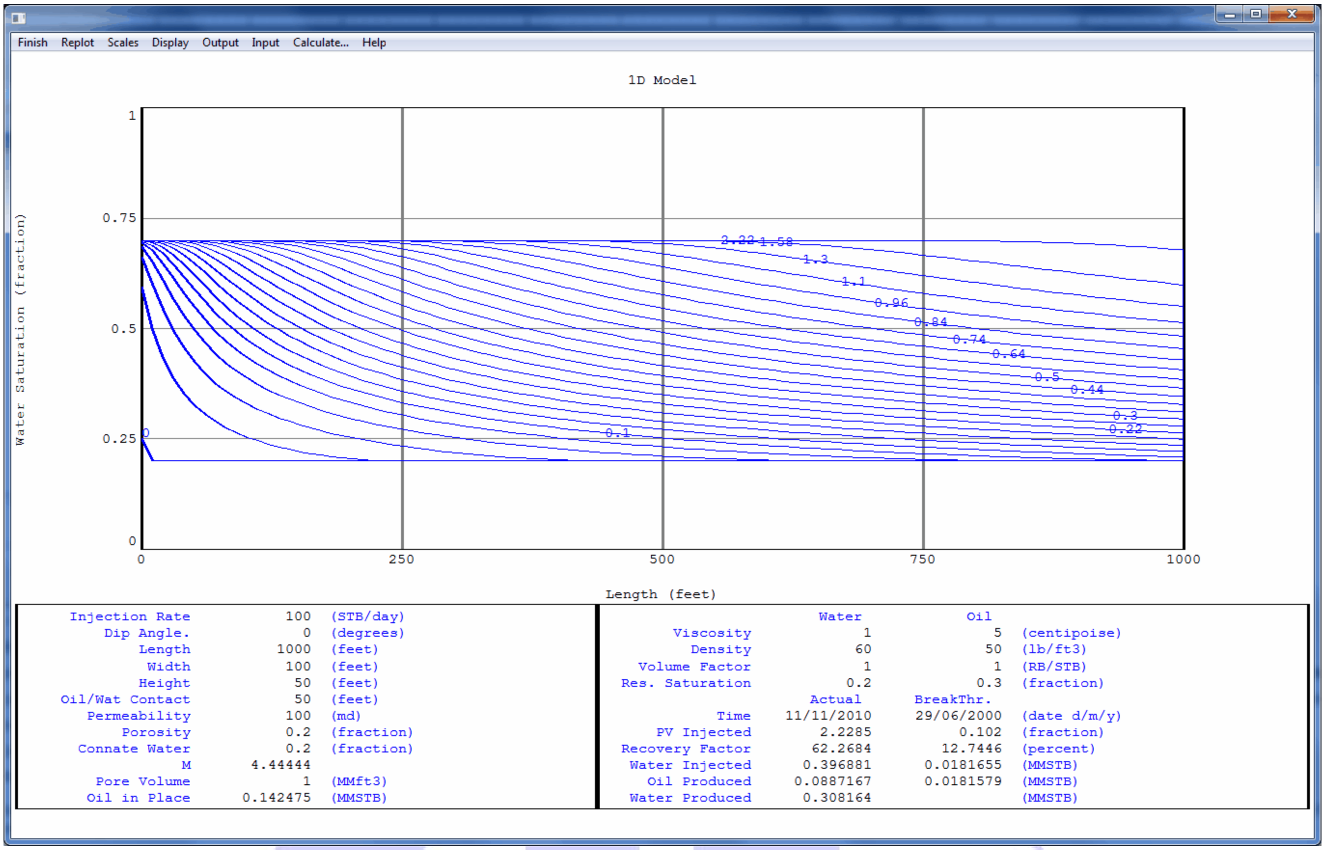
Residual Saturations	Defines respectively: • The residual saturation for the oil phase, • The critical saturation for the gas phase
End Points	Defines the relative permeability at its maximum saturation for each phase. For example for the oil, it corresponds to its relative permeability at So = (1 - Swc)
Corey Exponents	Defines the shape of relative permeability curve between the residual saturation and maximum saturation for each phase. See Relative Permeability Equations by Corey Exponent in Appendix B 483

Enter the relevant information, and click the **Plot** button to check the quality and validity of the data.

➲ *Please note that relative permeabilities are always represented as functions of water saturation.*

2.8.3.4 Running a Simulation

To run a simulation, choose **Calculations|Run simulation**, or press **ALT C R,** a screen (as seen below) will appear:



```
     Injection Rate          100   (STB/day)
         Dip Angle.            0   (degrees)
             Length         1000   (feet)
              Width          100   (feet)
             Height           50   (feet)
    Oil/Wat Contact           50   (feet)
       Permeability          100   (md)
           Porosity          0.2   (fraction)
      Connate Water          0.2   (fraction)
                  M      4.44444
        Pore Volume            1   (MMft3)
       Oil in Place     0.142475   (MMSTB)
```

```
                          Water           Oil
          Viscosity           1             5   (centipoise)
            Density          60            50   (lb/ft3)
      Volume Factor           1             1   (RB/STB)
    Res. Saturation         0.2           0.3   (fraction)
                         Actual     BreakThr.
               Time  11/11/2010    29/06/2000   (date d/m/y)
        PV Injected      2.2285         0.102   (fraction)
    Recovery Factor     62.2684       12.7446   (percent)
     Water Injected    0.396881     0.0181655   (MMSTB)
       Oil Produced   0.0887167     0.0181579   (MMSTB)
     Water Produced    0.308164                 (MMSTB)
```

The display shows most of the input parameters. Click **Calculate** from the window menu to start a simulation run.

The program displays the change in the distribution of the injected phase saturation. Each curve represents a distribution of saturations for a given pore volume injected (indicated on the plots as **PV injected**).

The calculation can be stopped at any time by clicking the **Abort** button. If the calculations are not stopped, the program ends the simulation at the cut-off value entered in the 'Reservoir and Fluids Parameters' dialogue box.

The bottom right portion of the screen displays the values of different parameters at breakthrough and at the end of the simulation.

Input parameters can be accessed throughout the **Input** menu option. When changes to the input parameters are completed, press **Calculate** to start a new simulation.

Full details of the calculations behind the plot can be viewed by choosing **Output - Result**. They may be printed and plotted differently using any of the options provided.

To change the variables plotted on the axes, click the **Variable** plot menu option. A dialogue box appears which allows the desired X and Y to be selected and plotted. Two variables can be selected from the left list column (**Y**) and one from the right list column (**X**).

To select a variable item, simply click the variable name, and use the space bar to select or de-select a variable item. The program will not allow more than two variables to be selected from the Y axis at one time

2.8.3.4.1 Plotting a Simulation

To view other calculated parameters, choose **Output|Result|Plot**. To change the variables plotted on the axes, click the **Variable** plot menu option. A dialogue box appears which allows selection of which X and Y variables are to be plotted. Two variables can be selected from the left list column (**Y**) and one from the right list column (**X**).

To select a variable item, click the variable name, or use the ↑ and ↓ arrow keys, and use the space bar to select or de-select a variable item. The program will not allow more than two variables to be selected from the Y axis at one time.

➲ If 2 variables have already been selected for the Y axis and one of them is to altered, first de-select the unwanted variable, and then choose the new plot variable.

2.8.4 1 D Model with EOR

2.8.4.1 Technical Description

1D Model with EOR

The 1D model has been modified to model various EOR methods.

- These are scoping tools i.e. they perform approximate calculations to allow quick comparison of different flood methods and the magnitude of the difference they may make to the sweep efficiency.
- Not a tool to be used to take a final decision. Detailed simulation with numerical simulators such as Reveal would then be required.
- Excellent training tool.
- Most useful in reservoirs with high Sro and high oil viscosity

2.8.4.1.1 Polymer

A polymer will increase the water viscosity. This gives a lower Fw and so a more favourable sweep efficiency. In MBAL, for the 1-D Model with polymer, the polymer modifies the water viscosity and can partition into oil or absorb on the rock. Other polymer effects such as shear, temperature effects, inaccessible pore volume effects etc. are not modelled and are best accounted for in a specialised numerical simulator such as REVEAL.

The polymer is injected with the water in a specific concentration. The concentration may be varied during the flood. The user enters a table of apparent water viscosity vs polymer concentrations.

The polymer concentration is tracked in each cell. The polymer concentration in the water in each cell will modify the fractional flow of that cell.

Rock can absorb a certain amount of polymer defined by the rock adsorption coefficient. This absorbed polymer will not affect the fractional flow. Similarly the oil can absorb some of the polymer as defined by the partition coefficient. This absorbed quantity also does not affect the fractional flow. So the cell needs to have a polymer concentration above the amount absorbed in the rock and the oil to see any effect. So we need to keep track of how much polymer is adsorbed in the rock and the oil as well as the polymer in the water which does affect the fractional flow.

In particular the fractional flow is modified as follows:

The water viscosity is read from the table of viscosity vs concentration and used in the Fw calculation. Since the water viscosity is increased by the polymer, we decrease the water mobility which gives better sweep efficiency.

A reduction in the rel perm end point of the water is also modelled. This also reduces the water mobility and thus gives better sweep efficiency. The calculation is as follows:-

```
if  K < 100.0
    CKOZE = 0.2
else if K > 300.0
    CKOZE = 0.75
```

```
else
   CKOZE = 0.2 + 0.00275*( K - 100.0 )
REQ = sqr(9.869E-12*K/porosity/CKOZE)*( 1.0 – porosity )*1.0E4
RG2 = 0.5 * ratio of actual/maximum polymer adsorbed in the rock
FRIW = ( REQ/( REQ - RG2) ) ** 4
```

The idea is that if there is no polymer in the rock then the correction is 1.0 (i.e. no correction). As the ploymer in the rock increases we will get a large correction leading to a smaller Krw.

We then correct the water end point using:-
End Point = End Point / FRIW

2.8.4.1.2 Surfactant

Surfactants are surface active agents which have affinity for oil and water molecules. By partitioning between the water and oil phases, they help reduce the interfacial tensions between the fluids to very low levels which helps desaturate the rock of its residual saturations.

Although the way in which surfactant affects the fractional flow is different to the polymer, the method of tracking it is very similar. i.e. the rock and oil can adsorb the surfactant so we need to track the surfactant in the water, oil and rock. The surfactant affects the surface tension of the water. So we need to enter a table of surfactant concentration vs surface tension.

The method used to alter the fractional flow is as described in; Fulcher Jr JPT 2/85 - "Effect of Capillary number and its constituents on Two phase relative permeability curves"

The main effect of the surfactant is that it reduces the residual saturation. However it does also have some lesser effects on the oil and water end point. So often a combination of surfactant and polymer is used. The surfactant frees up trapped/residual oil and the polymer increases fluid mobility by helping to push it out of the reservoir.

2.8.4.1.3 Hot Water/Temperature effects

Water can be injected with different temperatures. A schedule of temperatures can be used over the flood period.

The temperature is tracked in each cell as the heated water passes through the reservoir. This temperature is then used in the PVT calculations of the water and oil which will affect the fractional flow calculation. It is not always clear if the addition of heated water will help or hinder recovery.

The user must also enter the specific heat of the rock. The model will take this into account when calculating how the temperature is tracked along the reservoir.

2.8.4.1.4 CO2

This is injection of water with CO2 dissolved in it. CO2 will dissolve in the oil increasing its mobility. This reduces the fractional flow of water hence increasing recovery.

CO2 in oil mainly affects the oil viscosity. If the reservoir is deviated then it also affects the effective oil density of the fluid in the cell and hence the gravity term in the Fw calculation.

In MBAL, a table of reduction in oil viscosity vs CO2 concentration in oil is entered. A lookup table is then used to determine the change in oil viscosity for each cell.

The maximum CO2 that can be dissolved in the oil is also entered.

The effective oil density is calculated from a weighted average of the oil and CO2 in the oil i.e.

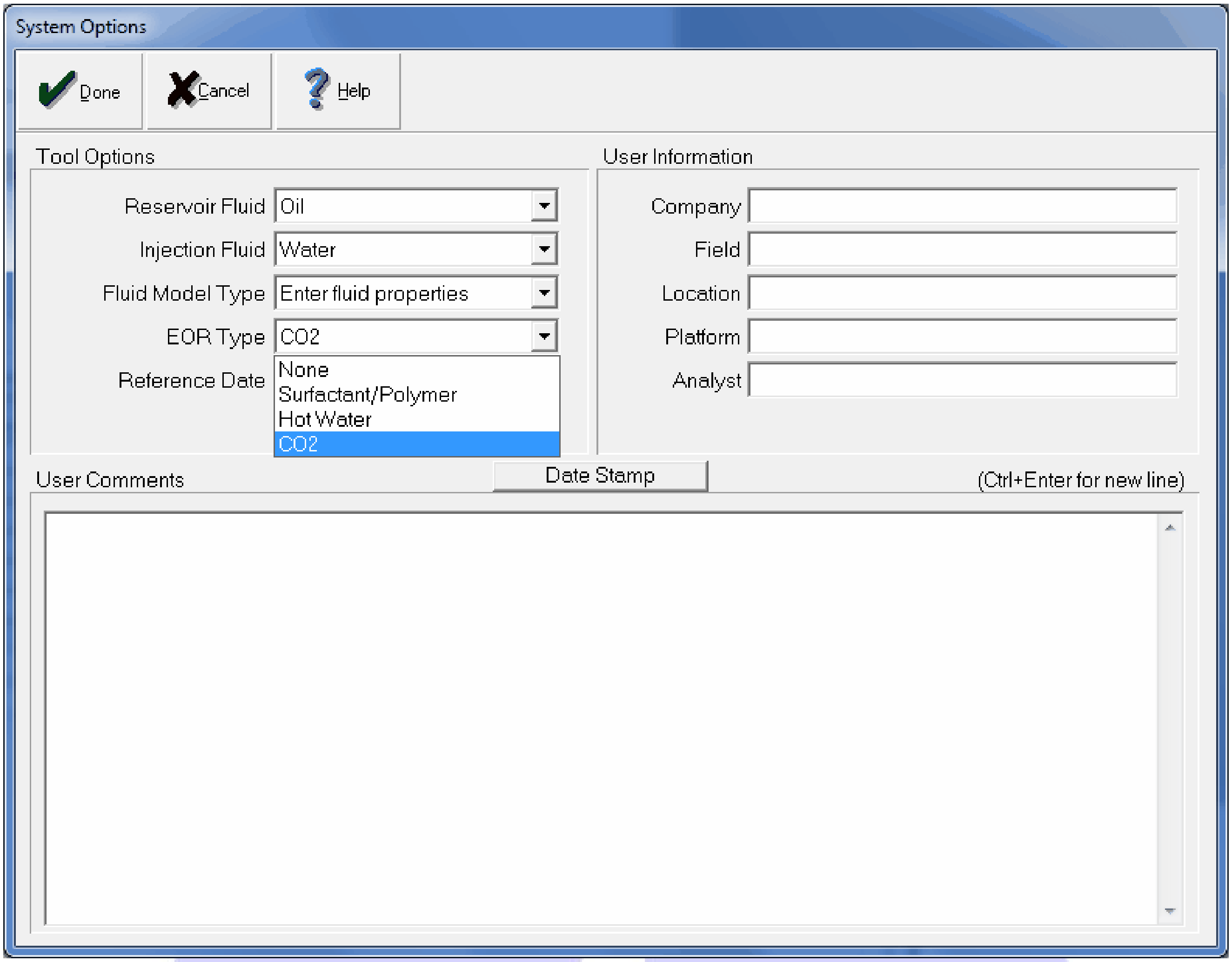
Voil = Bo * (1.0 – CO2 in oil)
VCO2 = Bg * CO2 in oil
RhoOilEffective = (Voil*RhoOil + VCO2*RhoGas)/(VOil + VCO2)

The tracking is done as follows. We assume that any CO2 dissolved in water will instead dissolve in the oil. However this will only occur up to the maximum fraction entered by the user. Once the oil is saturated with CO2 the CO2 will remain in the water.

Please note that MBAL does not take into account more detailed CO2 effects such as chemistry effects, rock mechanic effects e.t.c. These are best accounted for in REVEAL.

2.8.4.2 EOR properties

Depending on which EOR property is of interest, this can be selected from the "Options" section of the 1D model. The options include Surfactant polymer injection, Hot water injection and CO2 injection.


System Options
Done
Cancel
Help
Tool Options
User Information
Date Stamp
(Ctrl+Enter for new line)
User Comments

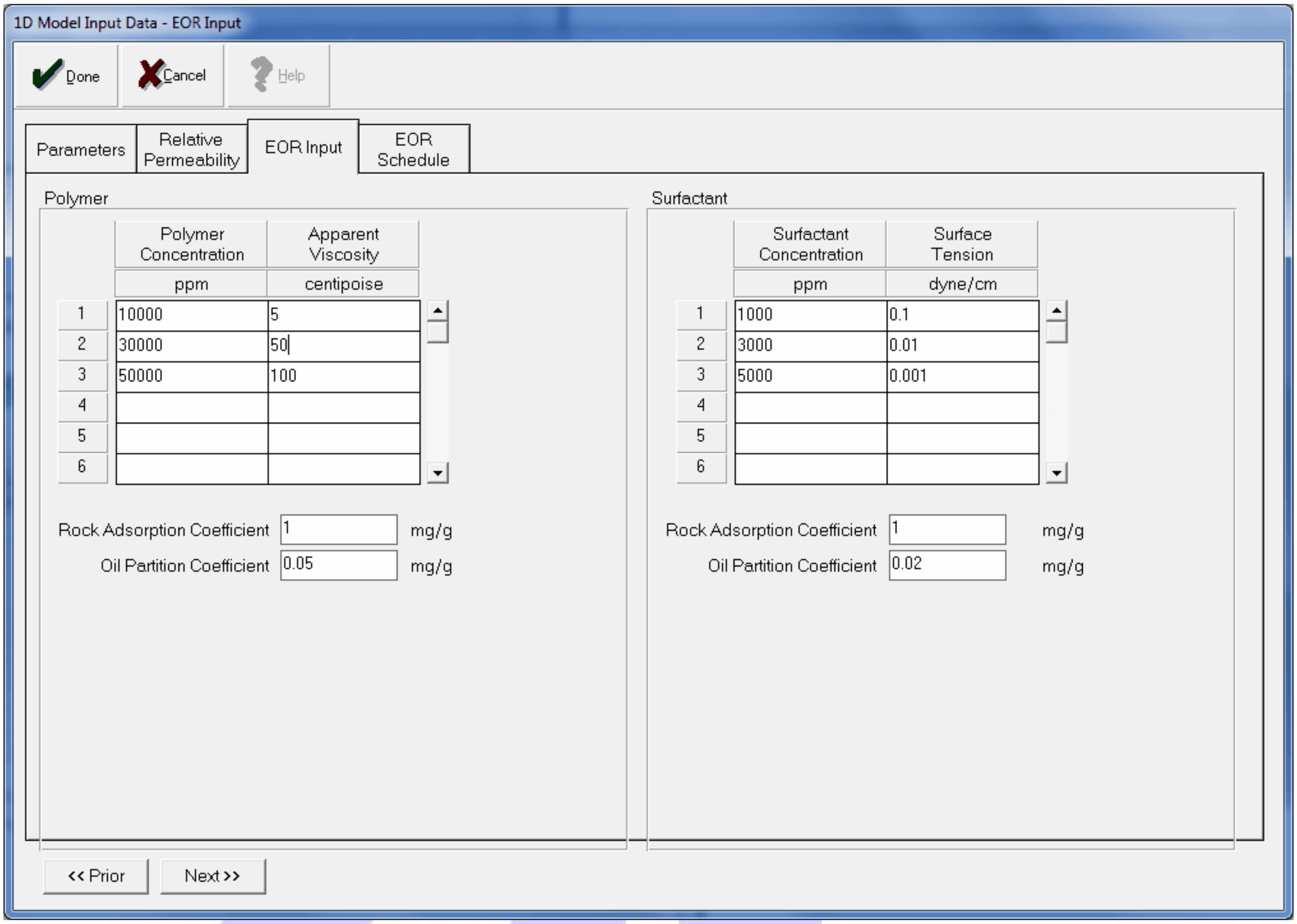
Reservoir Fluid: Oil
Injection Fluid: Water
Fluid Model Type: Enter fluid properties
EOR Type: CO2
Reference Date
None
Surfactant/Polymer
Hot Water
CO2

Company
Field
Location
Platform
Analyst

2.8.4.3 Surfactant/Polymer

Surfactant/Polymer

Polymer and surfactant data will be entered under "EOR" input tab. This is available within the "Input data" section. The reservoir parameters and relative permeability data required is similar to entry for the basic 1D model. More information is available in Reservoir and Fluids Properties 386 and Relative Permeability 389. For polymers, enter Polymer concentration versus apparent viscosity data while for surfactants, enter Surfactant concentration versus surface tension. The adsorption and oil partition co-efficients for both should be entered to calculate the effective concentrations and hence the fractional flow.


1D Model Input Data - EOR Input
Done
Cancel
Help
Parameters
Relative Permeability
EOR Input
EOR Schedule
<< Prior
Next >>

Polymer

	Polymer Concentration	Apparent Viscosity
	ppm	centipoise
1	10000	5
2	30000	50
3	50000	100
4		
5		
6		

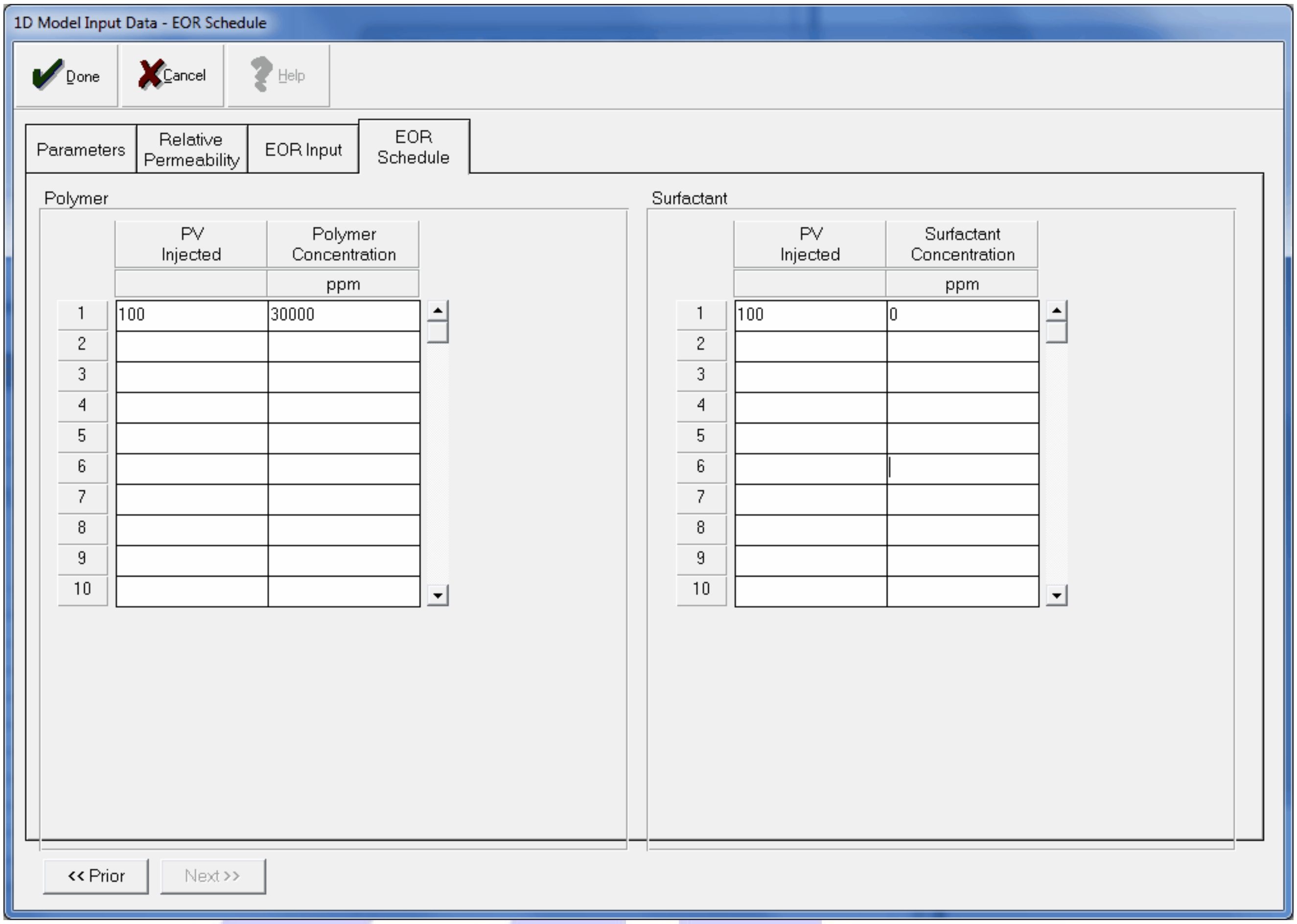
Rock Adsorption Coefficient 1 mg/g
Oil Partition Coefficient 0.05 mg/g

Surfactant

	Surfactant Concentration	Surface Tension
	ppm	dyne/cm
1	1000	0.1
2	3000	0.01
3	5000	0.001
4		
5		
6		

Rock Adsorption Coefficient 1 mg/g
Oil Partition Coefficient 0.02 mg/g

For the EOR schedule, enter the various PV injected for polymer and/or surfactants including the respective concentrations. The schedule can be used to define polymer injection alone, surfactant injection alone or combined surfactant/polymer injection. Below shows polymer alone injection schedule.


1D Model Input Data - EOR Schedule
Done
Cancel
Help
Parameters
Relative Permeability
EOR Input
EOR Schedule
<< Prior
Next >>

Polymer

	PV Injected	Polymer Concentration
		ppm
1	100	30000
2		
3		
4		
5		
6		
7		
8		
9		
10		

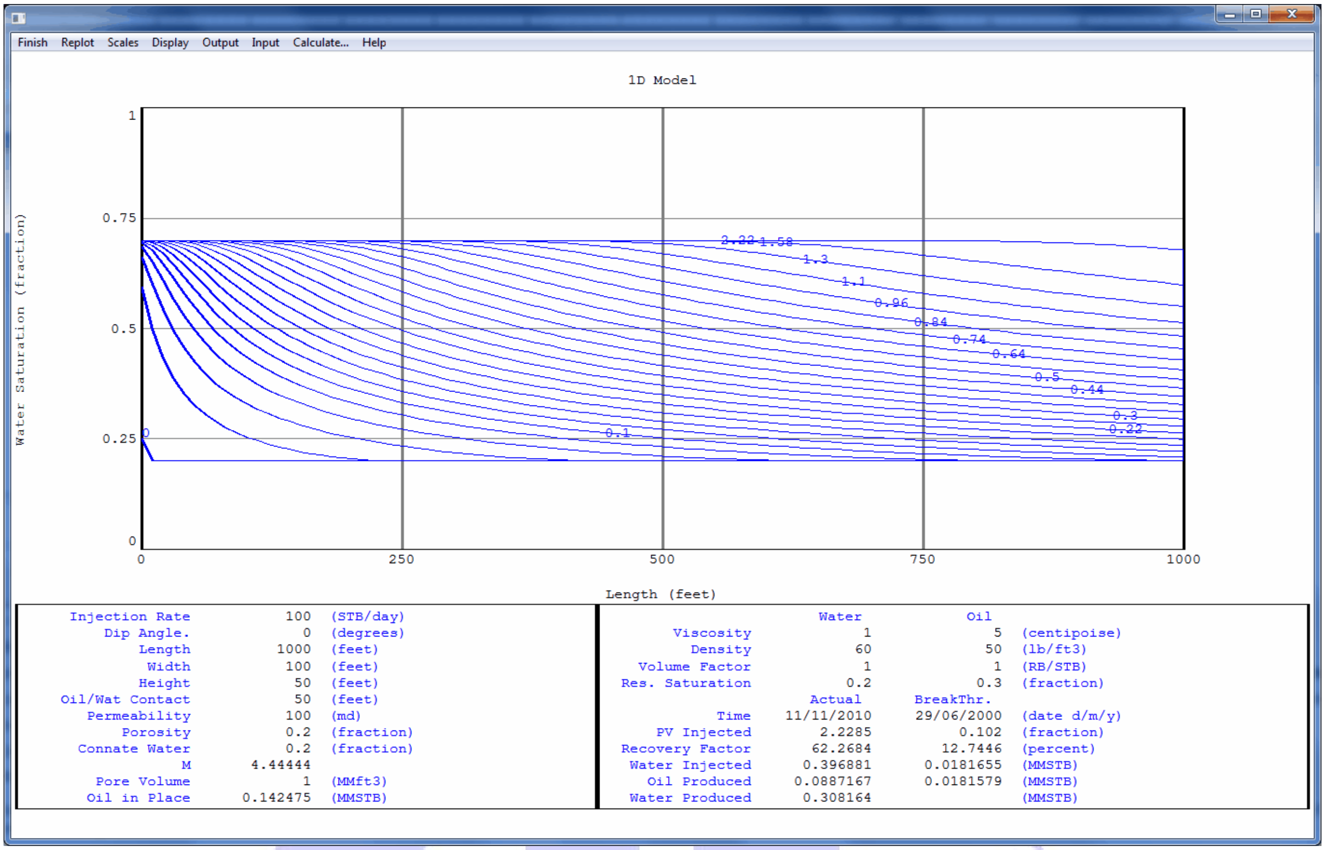
Surfactant

	PV Injected	Surfactant Concentration
		ppm
1	100	0
2		
3		
4		
5		
6		
7		
8		
9		
10		

Results

Example simulation results for polymer injection only as well as surfactant flood are shown below. The 1D waterflood result for the same model is also shown as base-case. The polymer injection shows an initial water front before the polymer front. The polymer shows a sharper shock front due to the increased mobility of the fluid and lower PV injected to mobilise the oil down to the residual saturations. The surfactant injection model also shows initial water front before surfactant front. More importantly, there is desaturation the fluids below the residual oil saturation giving increased fluid recovery when using surfactants.

Waterflood

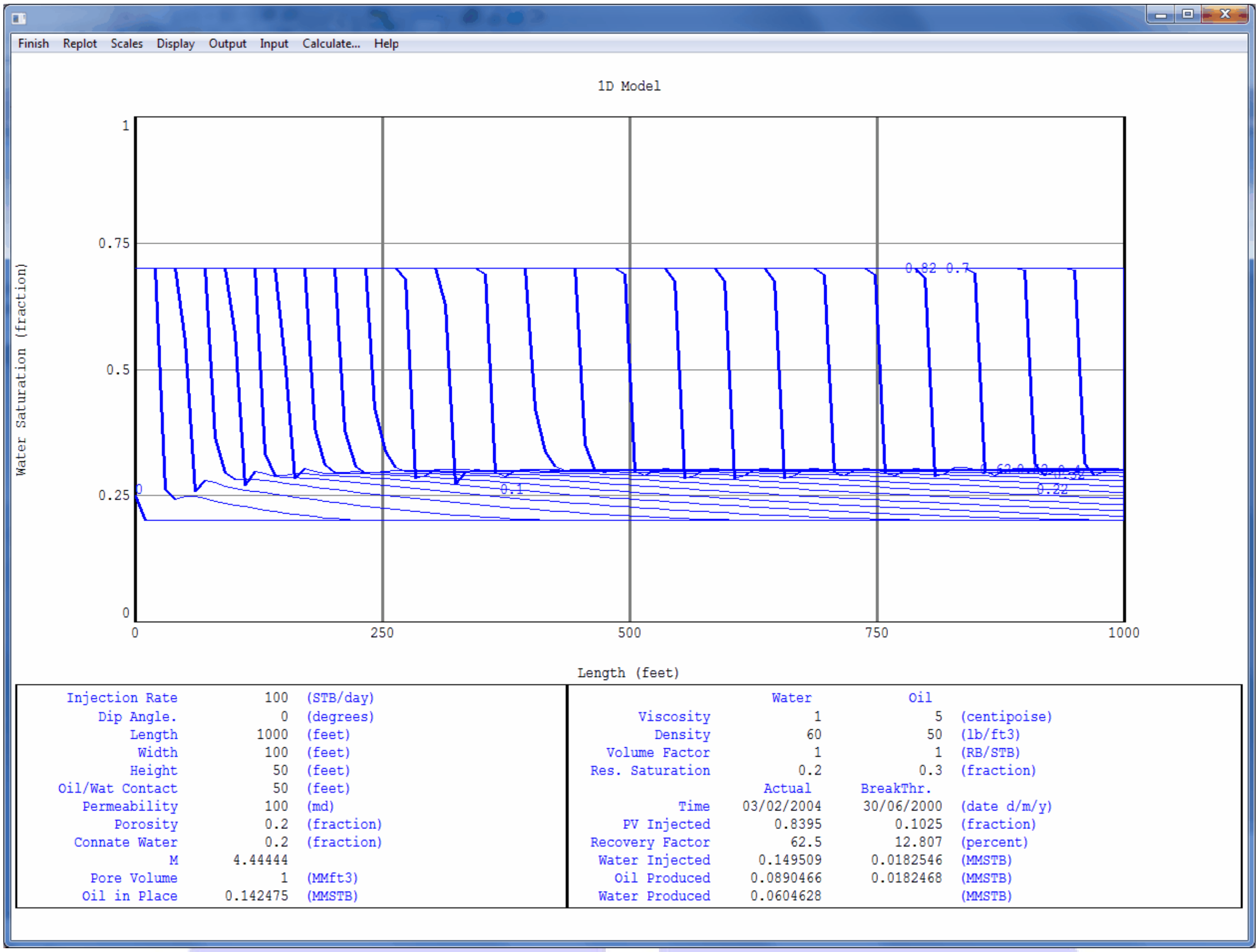


Finish Replot Scales Display Output Input Calculate... Help
1D Model
Water Saturation (fraction)
1
0.75
0.5
0.25
0
Length (feet)
0
250
500
750
1000
2.22
1.58
1.3
1.1
0.96
0.84
0.74
0.64
0.5
0.44
0.3
0.22
0.1
0

```
   Injection Rate         100  (STB/day)
      Dip Angle.            0  (degrees)
           Length        1000  (feet)
            Width         100  (feet)
           Height          50  (feet)
 Oil/Wat Contact           50  (feet)
     Permeability         100  (md)
         Porosity         0.2  (fraction)
    Connate Water         0.2  (fraction)
                M     4.44444
      Pore Volume           1  (MMft3)
     Oil in Place    0.142475  (MMSTB)
```

```
                        Water          Oil
        Viscosity           1            5  (centipoise)
          Density          60           50  (lb/ft3)
    Volume Factor           1            1  (RB/STB)
  Res. Saturation         0.2          0.3  (fraction)
                       Actual    BreakThr.
             Time  11/11/2010   29/06/2000  (date d/m/y)
      PV Injected      2.2285        0.102  (fraction)
  Recovery Factor     62.2684      12.7446  (percent)
   Water Injected    0.396881    0.0181655  (MMSTB)
     Oil Produced   0.0887167    0.0181579  (MMSTB)
   Water Produced    0.308164               (MMSTB)
```

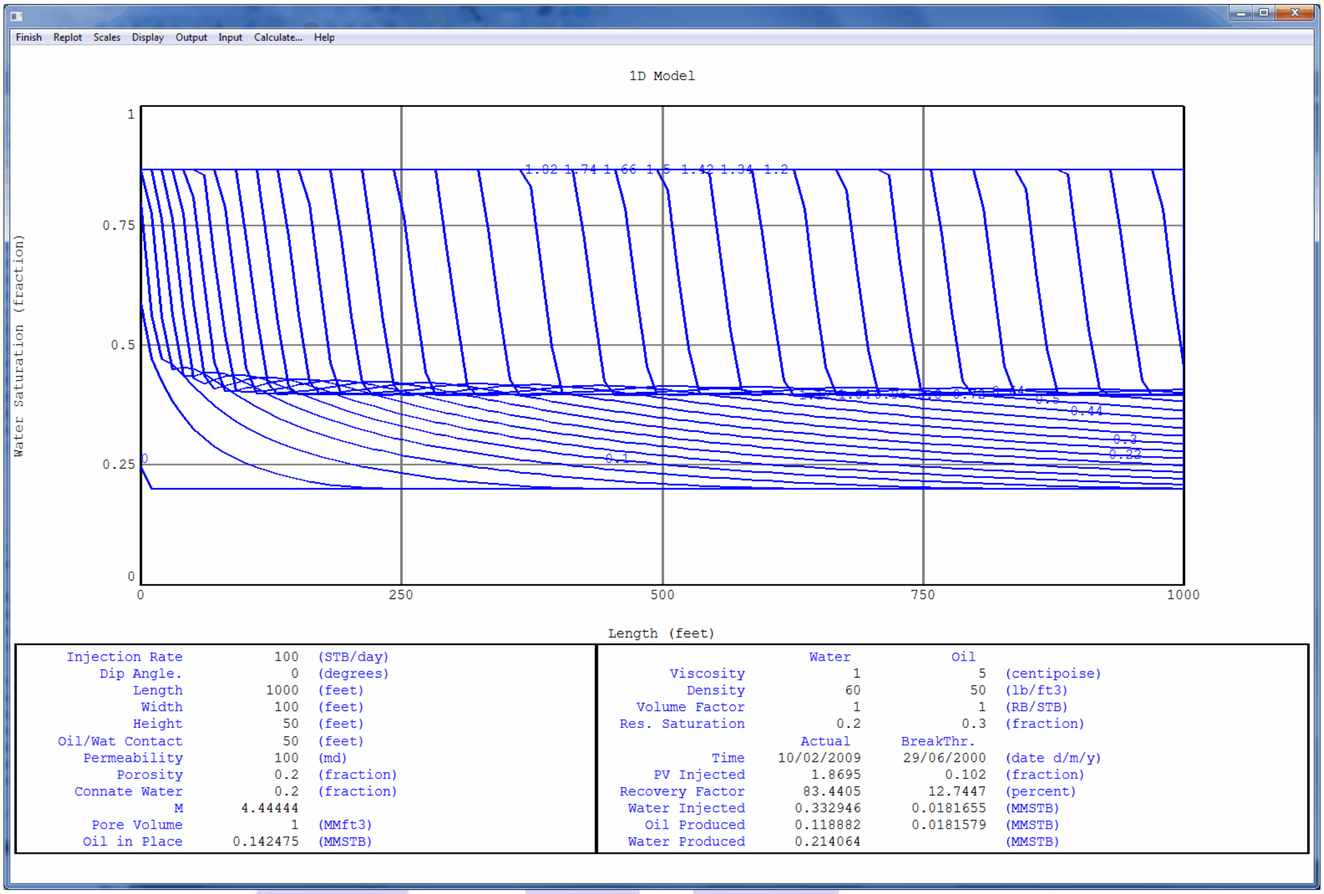
Polymer


Finish
Replot
Scales
Display
Output
Input
Calculate...
Help
1D Model
Water Saturation (fraction)
1
0.75
0.5
0.25
0
0
250
500
750
1000
Length (feet)
0.82
0.7
0.1
0.22

Injection Rate	100	(STB/day)
Dip Angle.	0	(degrees)
Length	1000	(feet)
Width	100	(feet)
Height	50	(feet)
Oil/Wat Contact	50	(feet)
Permeability	100	(md)
Porosity	0.2	(fraction)
Connate Water	0.2	(fraction)
M	4.44444	
Pore Volume	1	(MMft3)
Oil in Place	0.142475	(MMSTB)

	Water	Oil	
Viscosity	1	5	(centipoise)
Density	60	50	(lb/ft3)
Volume Factor	1	1	(RB/STB)
Res. Saturation	0.2	0.3	(fraction)
	Actual	BreakThr.	
Time	03/02/2004	30/06/2000	(date d/m/y)
PV Injected	0.8395	0.1025	(fraction)
Recovery Factor	62.5	12.807	(percent)
Water Injected	0.149509	0.0182546	(MMSTB)
Oil Produced	0.0890466	0.0182468	(MMSTB)
Water Produced	0.0604628		(MMSTB)

Surfactant

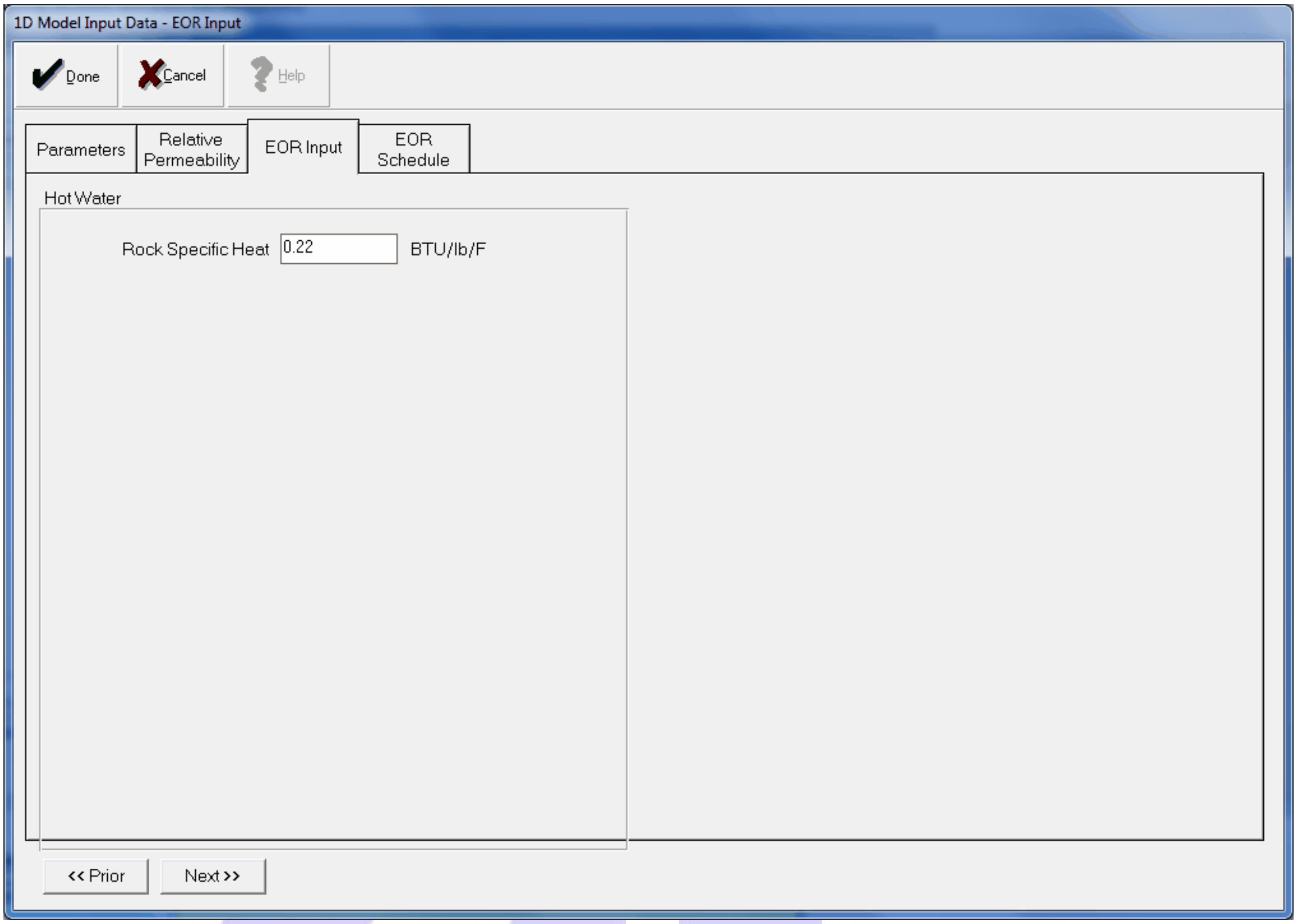

Finish
Replot
Scales
Display
Output
Input
Calculate...
Help
1D Model
Water Saturation (fraction)
1
0.75
0.5
0.25
0
0
250
500
750
1000
Length (feet)
1.82 1.74 1.66 1.5 1.42 1.34 1.2
0.44
0.3
0.22
0.1
0

```
     Injection Rate        100  (STB/day)                    Water         Oil
         Dip Angle.          0  (degrees)       Viscosity        1           5  (centipoise)
             Length       1000  (feet)            Density       60          50  (lb/ft3)
              Width        100  (feet)      Volume Factor        1           1  (RB/STB)
             Height         50  (feet)    Res. Saturation      0.2         0.3  (fraction)
    Oil/Wat Contact         50  (feet)                      Actual     BreakThr.
       Permeability        100  (md)                 Time 10/02/2009  29/06/2000  (date d/m/y)
           Porosity        0.2  (fraction)    PV Injected   1.8695       0.102  (fraction)
      Connate Water        0.2  (fraction) Recovery Factor  83.4405     12.7447  (percent)
                  M    4.44444              Water Injected 0.332946   0.0181655  (MMSTB)
        Pore Volume          1  (MMft3)       Oil Produced 0.118882   0.0181579  (MMSTB)
       Oil in Place   0.142475  (MMSTB)     Water Produced 0.214064               (MMSTB)
```

2.8.4.4 Hot Water/Temperature

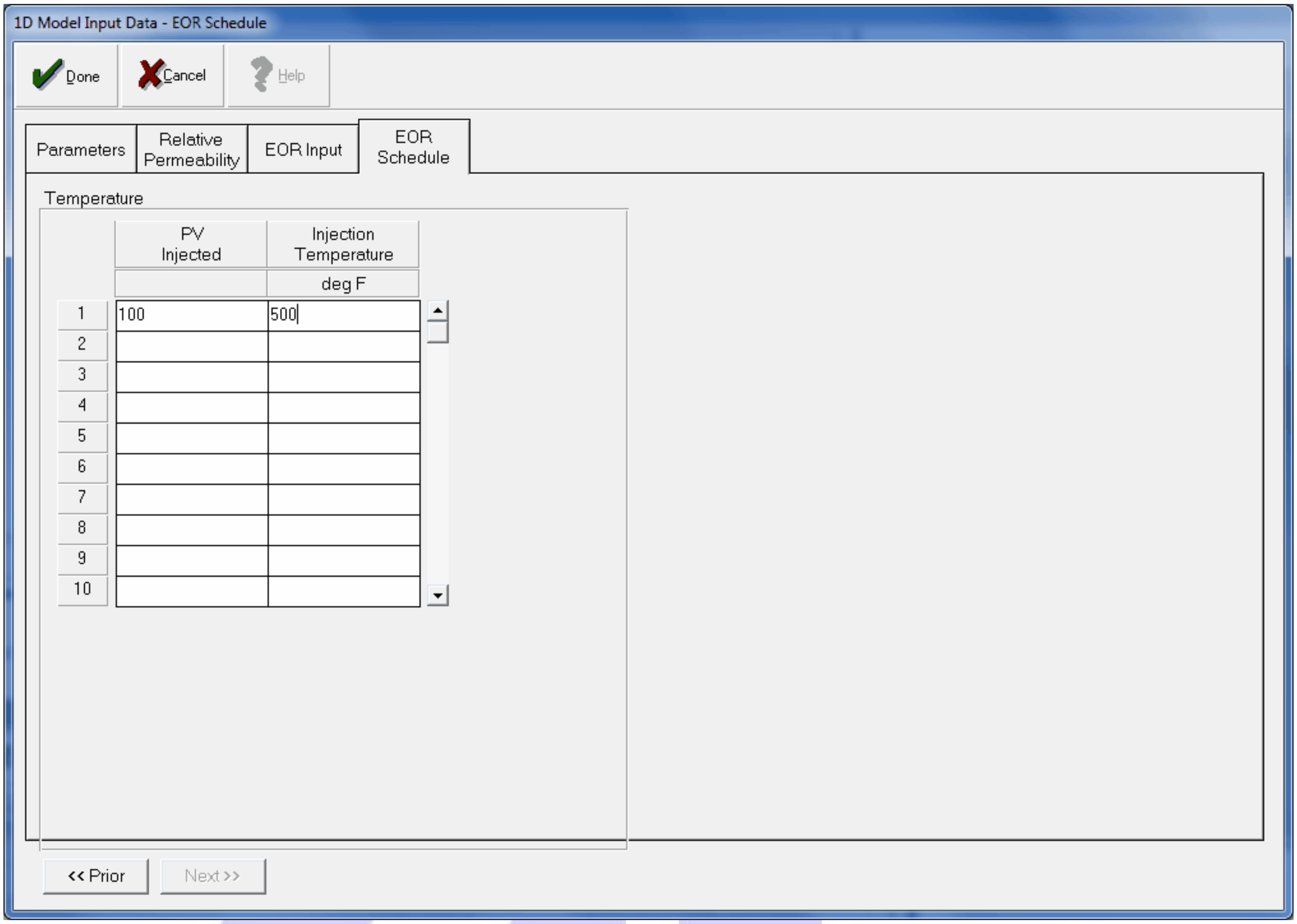
Hot Water/Temperature

Once 'Hot water' model is selected from the "Options" section of the 1D model, the data entry panel becomes available within the "Input data" section. The reservoir parameters and relative permeability data required is similar to entry for the basic 1D model. More information is available in Reservoir and Fluids Properties 386 and Relative Permeability 389. For the model, define the rock specific heat capacity to track the fluid temperature as the heated water progresses through the reservoir.


1D Model Input Data - EOR Input
Done
Cancel
Help
Parameters
Relative Permeability
EOR Input
EOR Schedule
Hot Water
<< Prior
Next >>

Rock Specific Heat 0.22 BTU/lb/F

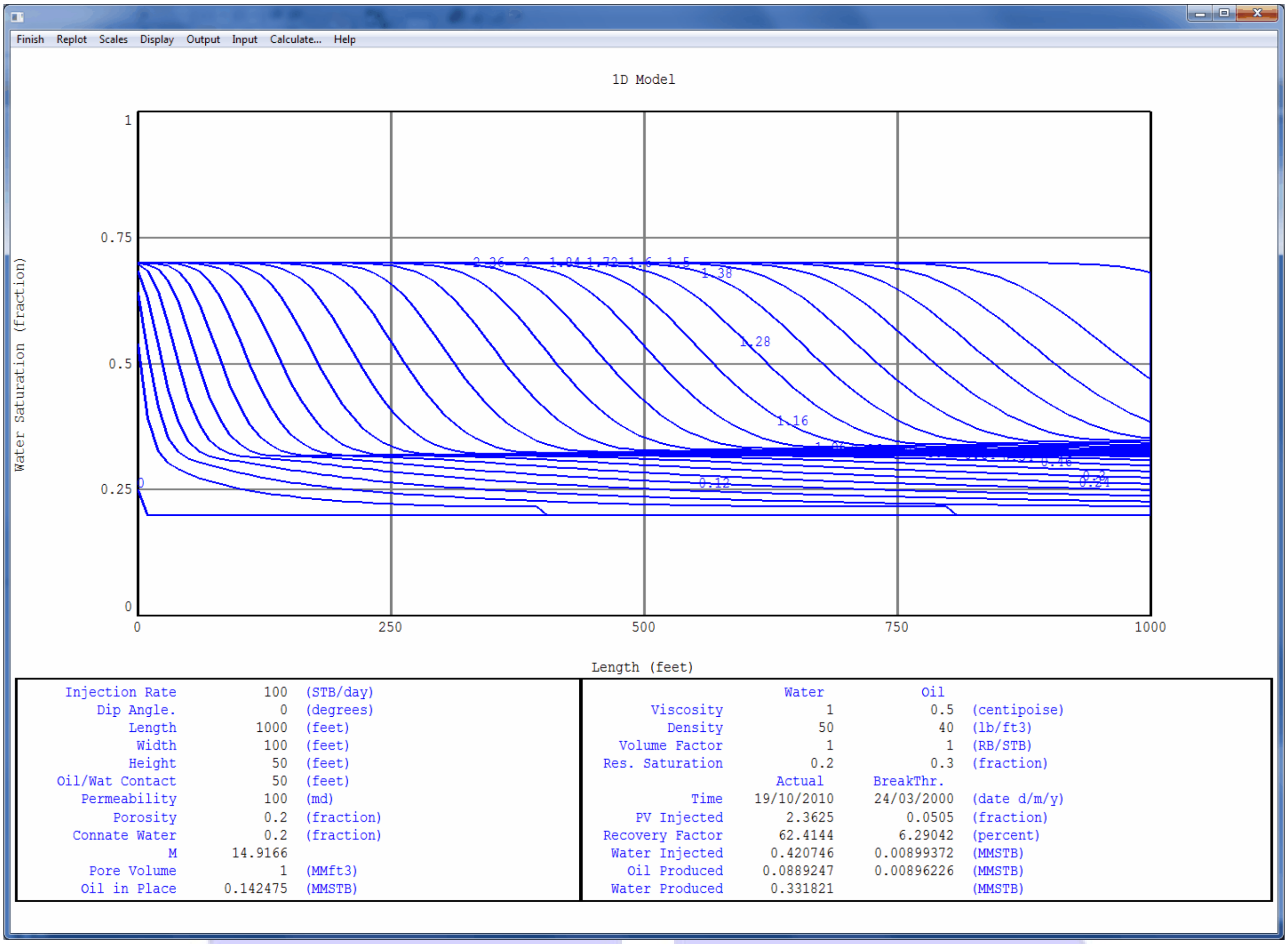
For the EOR schedule, enter the injected water temperature as a function of pore volumes injected.


1D Model Input Data - EOR Schedule
Done
Cancel
Help
Parameters
Relative Permeability
EOR Input
EOR Schedule
Temperature
<< Prior
Next >>

	PV Injected	Injection Temperature
		deg F
1	100	500
2		
3		
4		
5		
6		
7		
8		
9		
10		

Results

An example simulation result for hot water injection in 1 dimension is shown below. Temperature effects can modify both oil and water viscosity and hence can also increase or decrease recovery.


Finish
Replot
Scales
Display
Output
Input
Calculate...
Help
1D Model
Water Saturation (fraction)
1
0.75
0.5
0.25
0
250
500
750
1000
Length (feet)
2.26
2
1.84
1.72
1.6
1.5
1.38
1.28
1.16
0.12
0.24

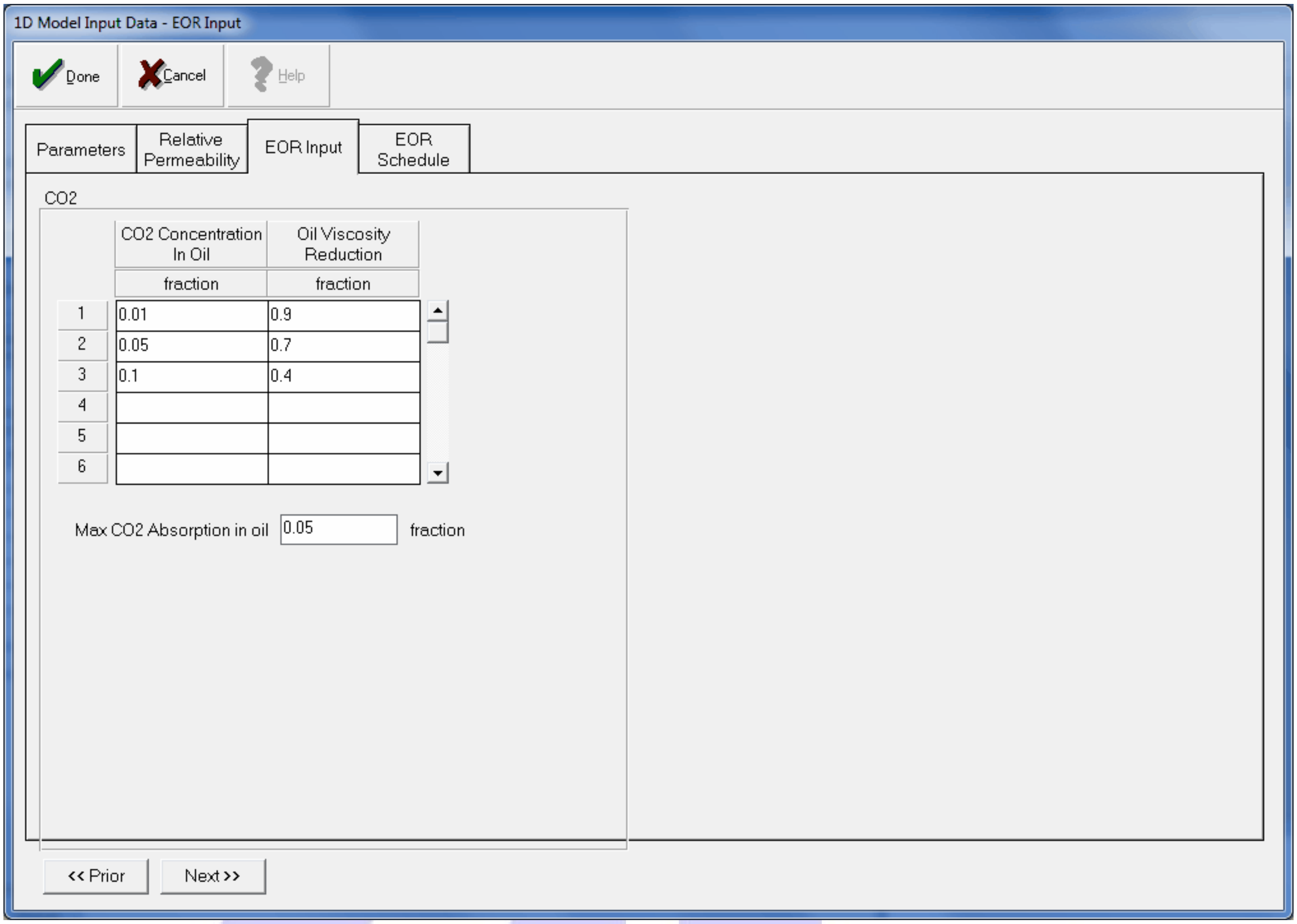
```
     Injection Rate         100  (STB/day)                         Water          Oil
         Dip Angle.           0  (degrees)           Viscosity        1          0.5  (centipoise)
             Length        1000  (feet)                Density       50           40  (lb/ft3)
              Width         100  (feet)          Volume Factor        1            1  (RB/STB)
             Height          50  (feet)        Res. Saturation      0.2          0.3  (fraction)
    Oil/Wat Contact          50  (feet)                          Actual     BreakThr.
       Permeability         100  (md)                     Time  19/10/2010  24/03/2000  (date d/m/y)
           Porosity         0.2  (fraction)        PV Injected     2.3625       0.0505  (fraction)
      Connate Water         0.2  (fraction)    Recovery Factor    62.4144      6.29042  (percent)
                  M     14.9166                 Water Injected   0.420746   0.00899372  (MMSTB)
        Pore Volume           1  (MMft3)          Oil Produced  0.0889247   0.00896226  (MMSTB)
       Oil in Place    0.142475  (MMSTB)        Water Produced   0.331821               (MMSTB)
```

2.8.4.5 CO2

CO2

Once CO2 injection model is selected from the "Options" section of the 1D model, the data entry panel becomes available within the "Input data" section. The reservoir parameters and relative permeability data required is similar to entry for the basic 1D model. More information is available in Reservoir and Fluids Properties 386 and Relative Permeability 389.

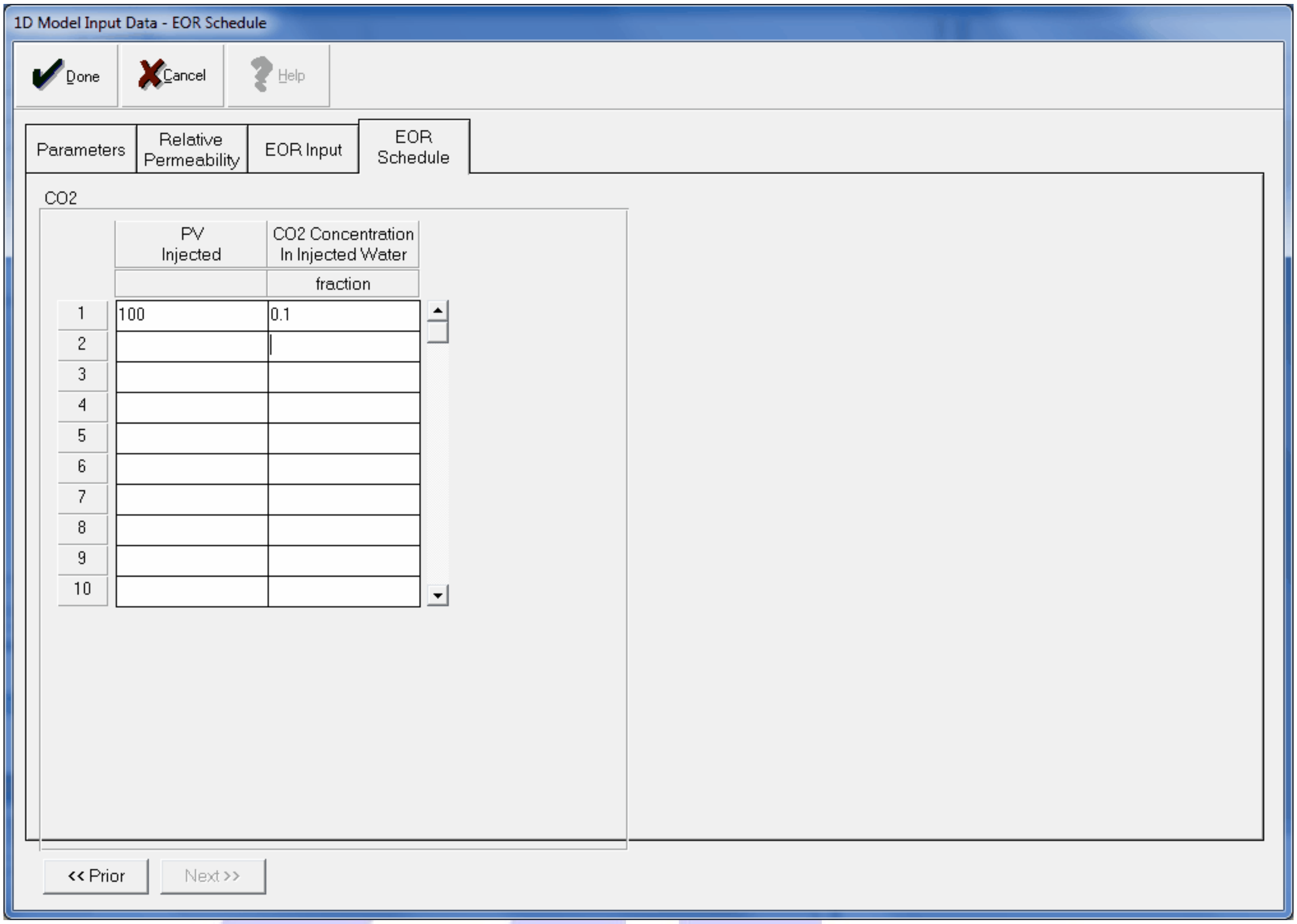
For CO2 injection, enter CO2 concentration in oil as a function of oil viscosity reduction. The maximum CO2 absorbed into the oil is also entered as a fraction.


1D Model Input Data - EOR Input
Done
Cancel
Help
Parameters
Relative Permeability
EOR Input
EOR Schedule
CO2
<< Prior
Next >>

	CO2 Concentration In Oil	Oil Viscosity Reduction
	fraction	fraction
1	0.01	0.9
2	0.05	0.7
3	0.1	0.4
4		
5		
6		

Max CO2 Absorption in oil 0.05 fraction

For the EOR schedule, enter the CO2 concentration in the injected water as a function of pore volumes injection.


1D Model Input Data - EOR Schedule
Done
Cancel
Help
Parameters
Relative Permeability
EOR Input
EOR Schedule
<< Prior
Next >>

CO2

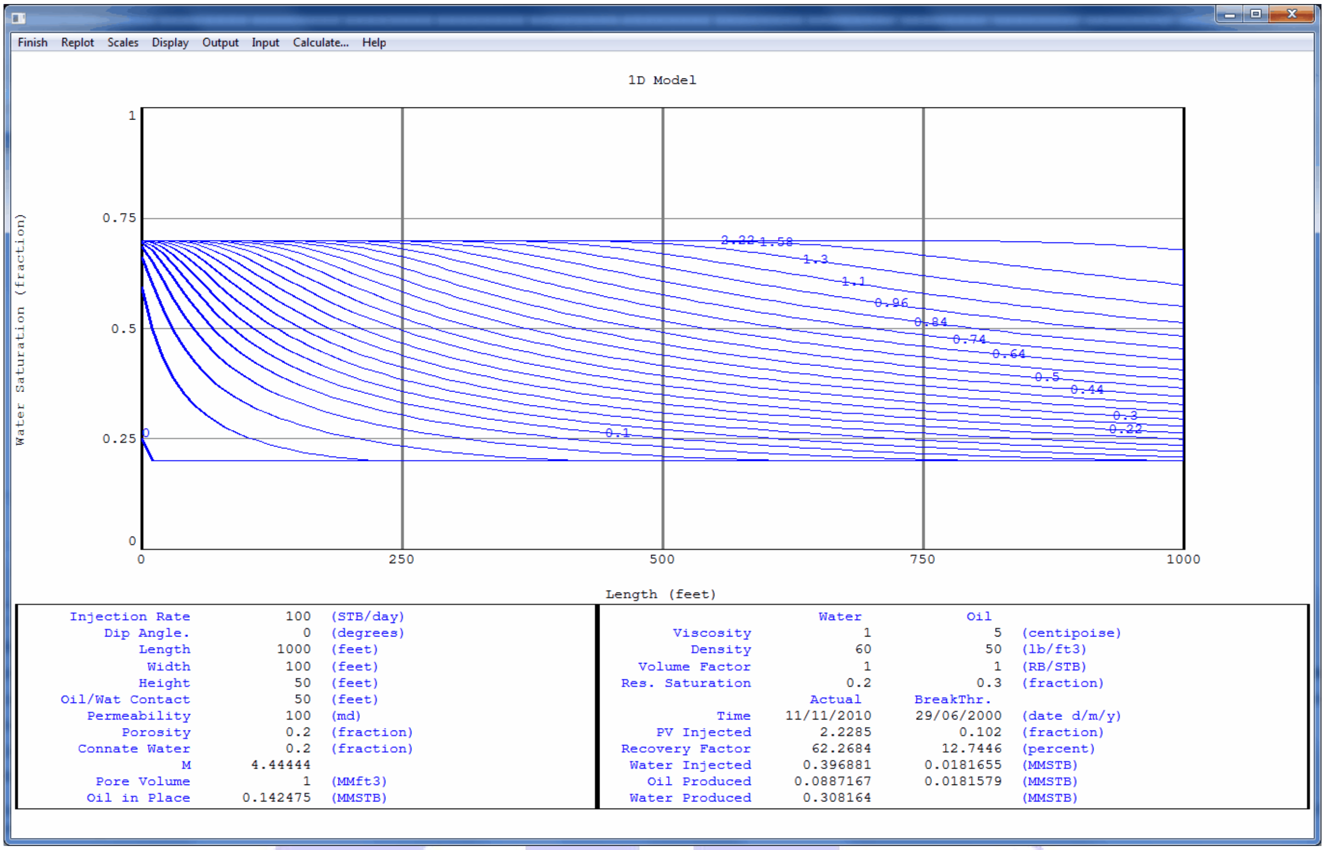
	PV Injected	CO2 Concentration In Injected Water
		fraction
1	100	0.1
2		
3		
4		
5		
6		
7		
8		
9		
10		

Results

An example simulation result for CO2 injection is shown below. The 1D waterflood result for the same model is also shown as base case. The assumption is that the CO2 concentration in the water becomes dissolved in the oil up to the maximum absorbed concentration specified. Based on the concentration in the oil, the reduction in oil viscosity is calculated from the table defined.

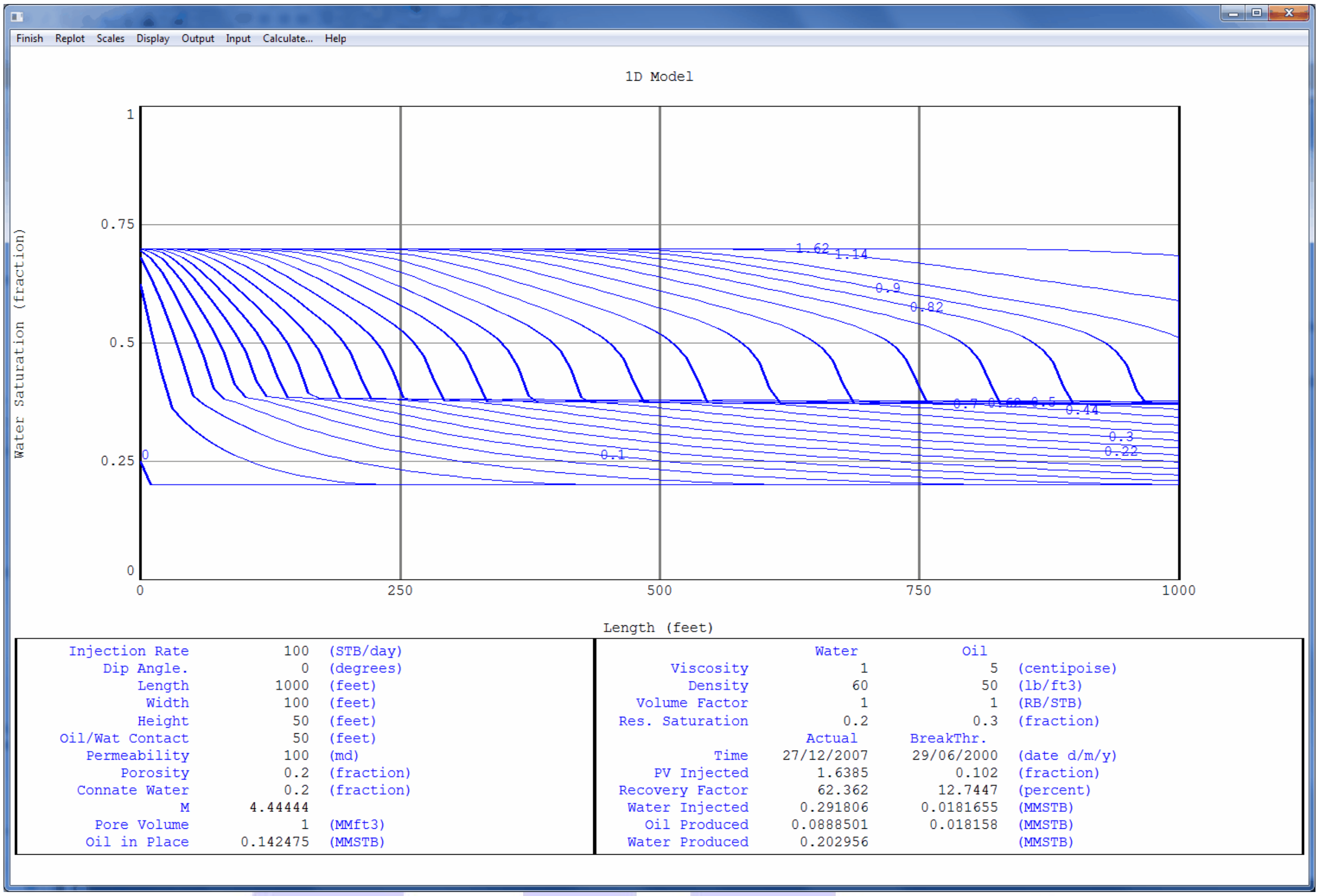
For CO2 flood, there is less pore volume injected for similar recovery as the waterflood. Please note that this is just a simple 1D analysis. CO2 injection involves more complex fluid chemical interactions between the injected fluids and the rock including geomechanical/rock mechanic effects. These are best studied in our specialised numerical simulation package - REVEAL.

Waterflood


Finish
Replot
Scales
Display
Output
Input
Calculate...
Help
1D Model
Water Saturation (fraction)
1
0.75
0.5
0.25
0
0
250
500
750
1000
Length (feet)
2.22
1.58
1.3
1.1
0.96
0.84
0.74
0.64
0.5
0.44
0.3
0.22
0.1
0

```
       Injection Rate          100  (STB/day)                              Water          Oil
           Dip Angle.            0  (degrees)              Viscosity           1            5  (centipoise)
               Length         1000  (feet)                   Density          60           50  (lb/ft3)
                Width          100  (feet)             Volume Factor           1            1  (RB/STB)
               Height           50  (feet)           Res. Saturation         0.2          0.3  (fraction)
     Oil/Wat Contact            50  (feet)                                Actual    BreakThr.
         Permeability          100  (md)                        Time  11/11/2010   29/06/2000  (date d/m/y)
             Porosity          0.2  (fraction)           PV Injected      2.2285        0.102  (fraction)
        Connate Water          0.2  (fraction)       Recovery Factor     62.2684      12.7446  (percent)
                    M      4.44444                    Water Injected    0.396881    0.0181655  (MMSTB)
          Pore Volume            1  (MMft3)             Oil Produced   0.0887167    0.0181579  (MMSTB)
         Oil in Place     0.142475  (MMSTB)           Water Produced    0.308164               (MMSTB)
```

CO2


Finish
Replot
Scales
Display
Output
Input
Calculate...
Help
1D Model
Water Saturation (fraction)
1
0.75
0.5
0.25
0
0
250
500
750
1000
Length (feet)
1.62
1.14
0.9
0.82
0.7
0.62
0.5
0.44
0.3
0.22
0.1
0

Injection Rate	100	(STB/day)
Dip Angle.	0	(degrees)
Length	1000	(feet)
Width	100	(feet)
Height	50	(feet)
Oil/Wat Contact	50	(feet)
Permeability	100	(md)
Porosity	0.2	(fraction)
Connate Water	0.2	(fraction)
M	4.44444	
Pore Volume	1	(MMft3)
Oil in Place	0.142475	(MMSTB)

	Water	Oil	
Viscosity	1	5	(centipoise)
Density	60	50	(lb/ft3)
Volume Factor	1	1	(RB/STB)
Res. Saturation	0.2	0.3	(fraction)
	Actual	BreakThr.	
Time	27/12/2007	29/06/2000	(date d/m/y)
PV Injected	1.6385	0.102	(fraction)
Recovery Factor	62.362	12.7447	(percent)
Water Injected	0.291806	0.0181655	(MMSTB)
Oil Produced	0.0888501	0.018158	(MMSTB)
Water Produced	0.202956		(MMSTB)

2.9 Multi Layer Tool

2.9.1 Programme Functions

The purpose of this tool is to generate pseudo relative permeability curves for multi-layer reservoirs using immiscible displacement. These can then be used by other tools in **MBAL** such as 'Material Balance'.

A single PVT description can be entered. A single pressure and temperature is entered for the reservoir which is used to calculate the required fluid properties.

Each layer has its own set of relative permeabilities, thickness and porosity.

The model considers the incline of the reservoir in all calculation types apart from the Stiles method.

The steps include:

- Specify the injection phase (gas or water)
- Specify the calculation type; Buckley-Leverett, Stiles, Communicating Layers or Simple.
- Enter the PVT description.

- Enter reservoir description
- Enter the layer description
- Calculate the production profile for each layer and combine all the layers into a consolidated production profile. Since we are only interested in the relative layer response, we use a dimensionless model wherever possible (e.g. length=1 foot and injection rate =1 cf/d).
- Calculate a pseudo relative permeability curve for the reservoir using the Fw/Fg match plot.

The final calculated results will be presented for each layer and for the overall system. If deemed necessary, the overall system results could be entered into a single layer Buckley-Leverett model.

2.9.2 Technical Background

There are four calculation types described below.

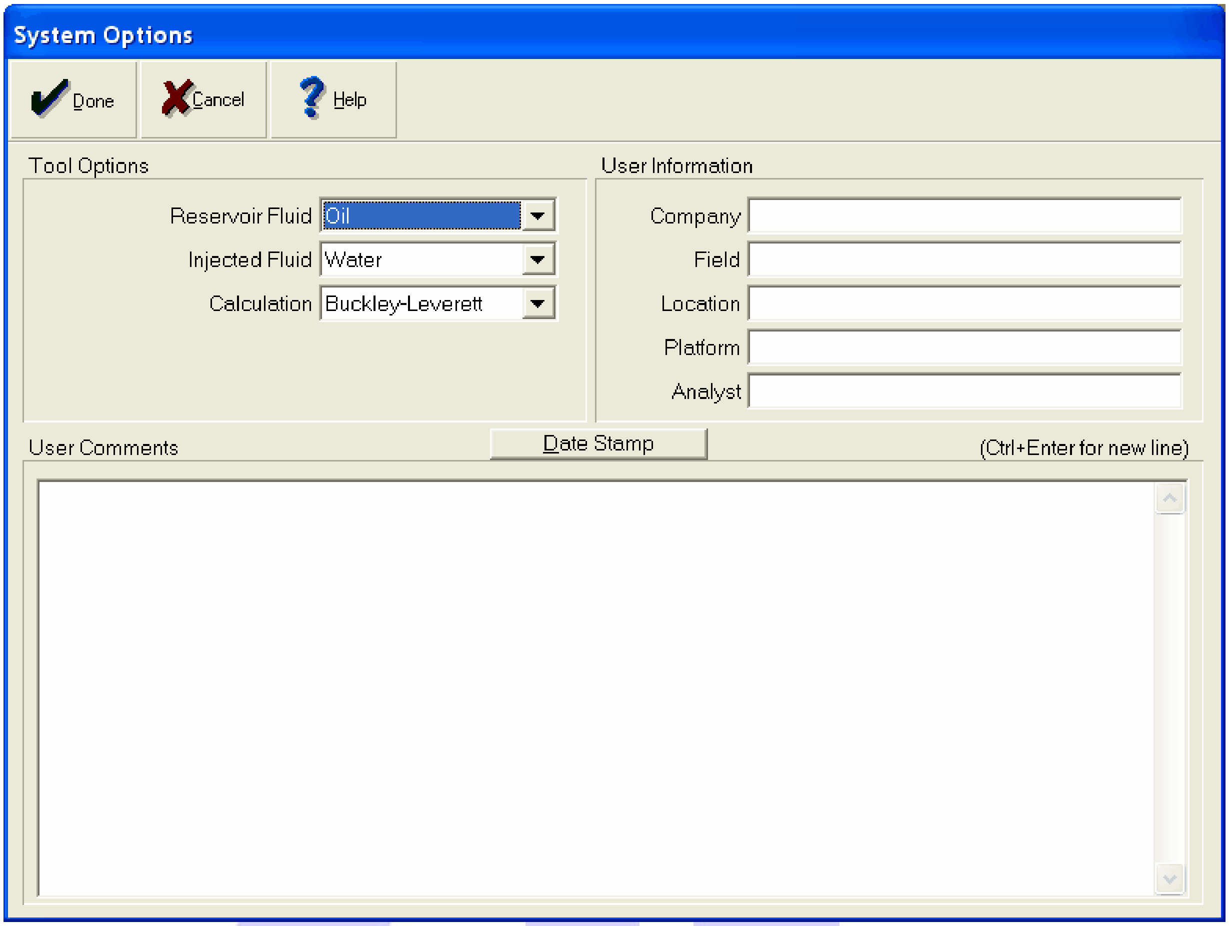
Buckley - **Leverett**	This calculation is based on the methods from "Buckley, S.E. and Leverett, M.C., 1942 Mechanism of Fluid Displacement in Sands. Trans. AIME. 146; 107-116." and "Welge, H.J., 1952. A Simplified Method for Computing Oil Recovery by Gas or Water drive. Trans. AIME. 195; 91-98." The model assumes the same pressure difference across the length of all layers. Therefore the unit dimensionless rate is distributed between layers proportionally to the kh of the layer. We assume dimensionless values in all other cases e.g. Width=Length=1.0. Note that if the dip angle is non-zero then the Fw or Fg calculation applies the gravitational correction. For this calculation it will use the rate and reservoir width entered in the reservoir parameters (the rate is again distributed proportionally to the kh of the layer. The program calculates the production profile of each layer individually and the results are output for time vs. Np, Gp/Wp, Qo, Qg/Qw, Wc/GOR and fluid properties. It then combines the production of each into a consolidated set of results for the whole reservoir using the artificial time frame as the reference points. The results are reported (as much as possible) at equal intervals of injection saturations
Stiles	This calculation is based on the method from "Stiles, W.E., 1949. Use of Permeability Distribution in Water Flood Calculations. Trans. AIME, 186:9." The model assumes the same pressure difference across the length of all layers. Therefore the unit dimensionless rate is distributed between layers proportionally to the kh of the layer. We assume dimensionless values in all other cases e.g. Width=Length=1.0. This method does not apply the gravitational correction to the calculation

	of Fw or Fg. The program calculates the production profile of each layer individually and the results are output for time vs. Np, Gp/Wp, Qo, Qg/Qw, Wc/GOR and fluid properties. In the case of Stiles this is a simple step function. It then combines the production of each into a consolidated set of results for the whole reservoir using the artificial time frame as the reference points. The results are reported (as much as possible) at equal intervals of injection saturations
Communicating Layers	This calculation is based on the method from "Dake, L.P., Fundamentals of Petroleum Engineering, and Section 10.8". Unlike the other multi-layer calculation types, this method does not first calculate separate responses for each layer. Instead it first calculates and reports the modified relative permeability tables taking the vertical distribution of saturations due to capillary pressure into account. It then calculates and reports the production profile of the complete reservoir using these modified relative permeability tables. Note that if the dip angle is non-zero then the Fw or Fg calculation (used to calculate the production profile) applies the gravitational correction. For this calculation it will use the rate and reservoir width entered in the reservoir parameters (the rate is again distributed proportionally to the kh of the layer. To run a Buckley-Leverett calculation using the modified relative permeability curves: • Run the communicating model as described above. • Go back to the options dialogue and change calculation type to Buckley-Leverett. • Go back to the layer input dialogue. • Delete all the layers using the 'Reset' button. • Click the 'Copy' button and select the "Multi Layers - Calculated from Communicating Stream". This layer has the table of relative permeabilities calculated taking into account the capillary pressures. • Run the calculation again
Simple	This calculation is a simple method of combining several layers to give the reservoir response. The single layer model performs a simple single cell simulation. It splits the calculation into a number of time steps. At each time steps it calculates the fractional flow at the production end based on the current saturations. It then updates the saturations in the cell based on these rates. In effect, it is similar to the 1D model with a single cell. If there is no dip angle then the result of the layer calculation will correspond exactly to the input relative permeability curves.

	Note that if the dip angle is non-zero then the Fw or Fg calculation applies the gravitational correction. For this calculation it will use the rate and reservoir width entered in the reservoir parameters (the rate is again distributed proportionally to the kh of the layer. The model assumes the same pressure difference across the length of all layers. Therefore the unit dimensionless rate is distributed between layers proportionally to the kh of the layer. We assume dimensionless values in all other cases e.g. Width=Length=1.0. The program calculates the production profile of each layer individually and the results are output for time vs. Np, Gp/Wp, Qo, Qg/Qw, Wc/GOR and fluid properties. It then combines the production of each into a consolidated set of results for the whole reservoir using the artificial time frame as the reference points. The results are reported (as much as possible) at equal intervals of injection saturations

2.9.3 Tool Options

On selecting 'Multi Layer' as the analysis tool in the 'Tool' menu, go to the 'Options' menu to define the primary fluid of the reservoir. This section describes the 'Tool Options' section of the 'System Options' dialogue box.


System Options
Done
Cancel
Help
Tool Options
User Information
Company
Field
Location
Platform
Analyst
User Comments
Date Stamp
(Ctrl+Enter for new line)

Reservoir Fluid: Oil
Injected Fluid: Water
Calculation: Buckley-Leverett

To select an option, click the arrow to the right of the field to display the current choices. To move to the next entry field, click the field to highlight the entry, or use the **TAB** button.

Input Fields

Reservoir Fluid	The fluid type is oil
Injected Fluid	This is the injected phase, which can be water or gas
Calculation	The user can select one of the four method available: • Buckley-Leverett • Stiles • Communicating Layers • SImple

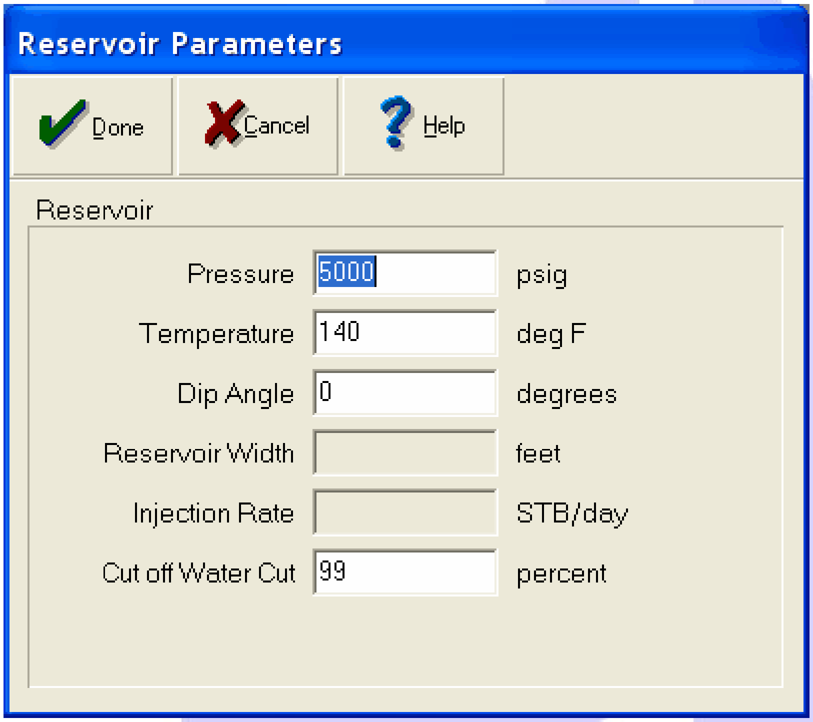
Supply the header information and any comments about this analysis in the appropriate boxes. Click ***Done*** to accept the choices and return to the main menu.

Two main menu options then become available:

Input	to enter the reservoir, fluids and injection parameters
Calculation	to run a simulation and produce result reports and plots

2.9.4 Reservoir parameters

This dialogue is used to enter the reservoir parameters required by the multi-layer tool.



Pressure 5000 psig
Temperature 140 deg F
Dip Angle 0 degrees
Reservoir Width feet
Injection Rate STB/day
Cut off Water Cut 99 percent

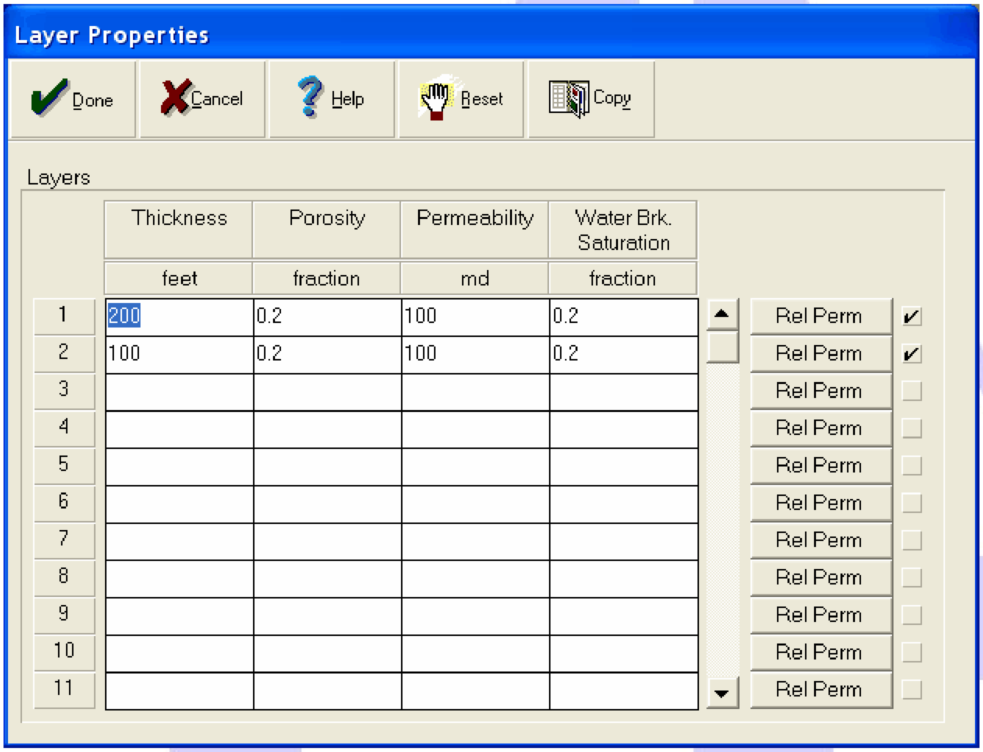
Input data

Pressure	This is used by the PVT model to calculate the fluid properties
Temperature	This is used by the PVT model to calculate the fluid properties
Dip Angle	This is used to correct the Fw or Fg curve. It is not used by the Stiles calculation type
Reservoir Width	This is only required if the dip angle is non-zero. This is because the gravitational correction is the only part of the calculation that requires a real value rather than a dimensionless value
Water/Gas Injection Rate	This is only required if the dip angle is non-zero. This is because the gravitational correction is the only part of the calculation that requires a real value rather than a dimensionless value

Cut off Water Cut/GOR	This value is used to stop the calculation of the consolidated production profile when the water cut/ GOR reaches a specific value. This can be used to significantly speed up the calculations
Connate Water	This value is only required if using gas injection

2.9.5 Layer Properties

To access the layer properties dialogue box, choose **Input|Layer Properties**.
A screen (as seen below) appears:



Layers

	Thickness	Porosity	Permeability	Water Brk. Saturation		
	feet	fraction	md	fraction		
1	200	0.2	100	0.2	Rel Perm	☑
2	100	0.2	100	0.2	Rel Perm	☑
3					Rel Perm	☐
4					Rel Perm	☐
5					Rel Perm	☐
6					Rel Perm	☐
7					Rel Perm	☐
8					Rel Perm	☐
9					Rel Perm	☐
10					Rel Perm	☐
11					Rel Perm	☐

Input Fields

Thickness	Thickness of the layer
Porosity	Porosity of the layer
Permeability	Absolute permeability of the layer
Water Brk. **Saturation**	Water breakthrough saturation for the layer. This field can be used to modify the relative permeabilities. The relative permeability curve will be shifted to start at the water breakthrough saturation instead of the Swc. This field can be left blank

Enter the information for each layer in the reservoir. Then click on the corresponding **Rel Perm** button to enter the relative permeability curve for each layer. A tick will appear next to the **Rel Perm** button to indicate that a valid relative permeability curve has been entered.

Command buttons

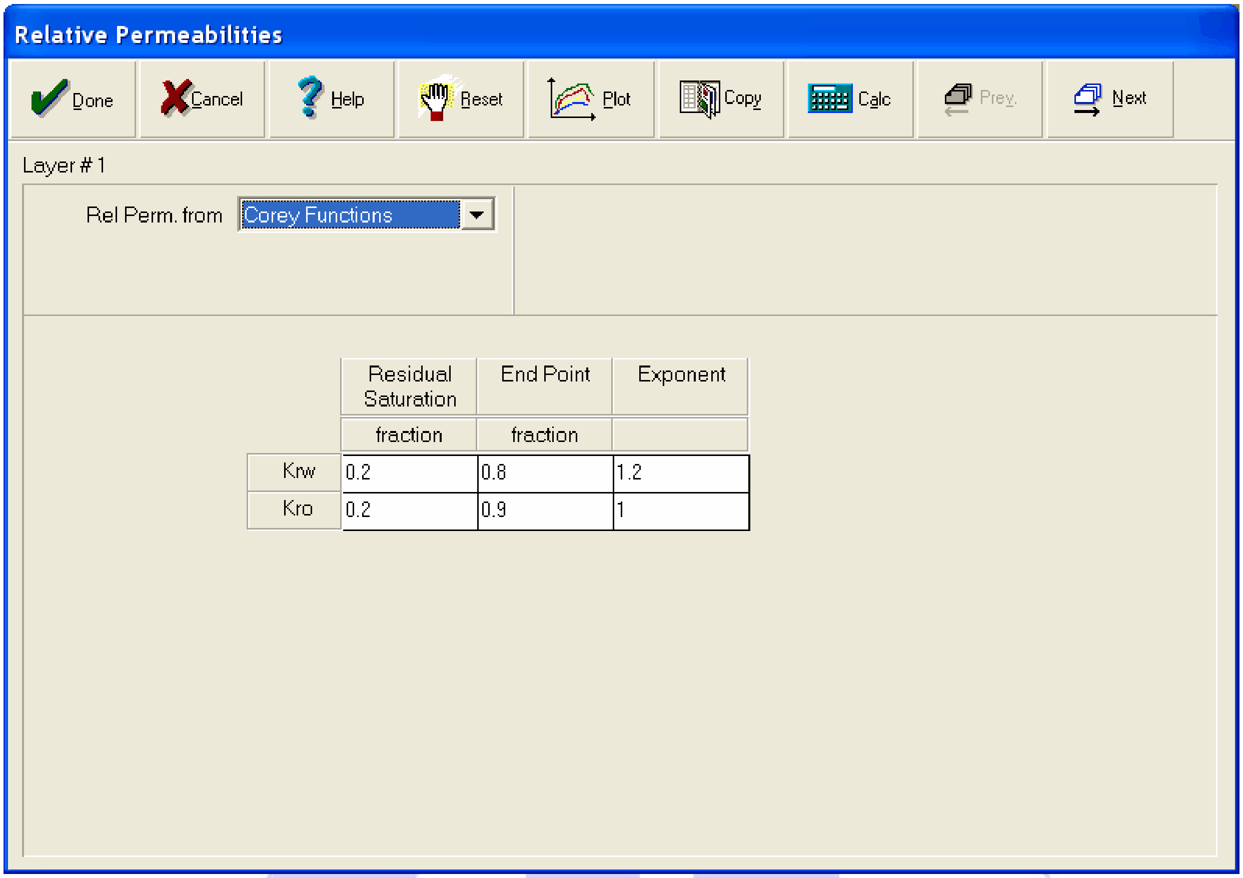
Reset	delete all the layers and their relative permeability curves
Copy	add an existing layer to the current list in this dialogue. The layer that can be added include: • Any layer already in the dialogue • Any pseudo-layer calculated by the multi-layer tool
Done	accept and return to the main menu

Click **Done** to accept and return to the main menu.

See Table Data Entry for more information on entering the properties.

2.9.5.1 Relative Permeability

To access the relative permeabilities dialogue box for a particular layer, click on the **Rel Perm** button. A screen similar to the following will appear.



Layer # 1

Rel Perm. from: Corey Functions

	Residual Saturation	End Point	Exponent
	fraction	fraction	
Krw	0.2	0.8	1.2
Kro	0.2	0.9	1

➲ *See Corey Relative Permeability Equations in Appendix B* 483

Input Fields

Rel Perm From	Select whether the relative permeabilities are to come from: • Corey Functions or • User Defined input tables
Residual Saturations	Defines respectively: • The connate saturation for the water phase • The residual saturation of the oil phase for water flooding These saturations are used to calculate the amount of oil 'by-passed' during a water flooding
End Points	Defines the relative permeability at its saturation maximum for each phase. For example for the oil, it corresponds to its relative permeability at So = (1-Swc)
Corey Exponents	Defines for each phase the relative permeability at its saturation maximum. For example for the oil, it corresponds to its relative permeability at So = (1-Swc)

Command Buttons

Reset	Reset the relative permeability curve
Plot	Displays the relative permeability tables in a graph.
Copy	Copy a relative permeability curve from another location in the program e.g. another layer.
Prev	Edit the rel perms for the previous layer in the table.
Next	Edit the rel perms for the next layer in the table.

Click ***Done*** to exit and return to the main menu screen, or ***Cancel*** to quit the screen.

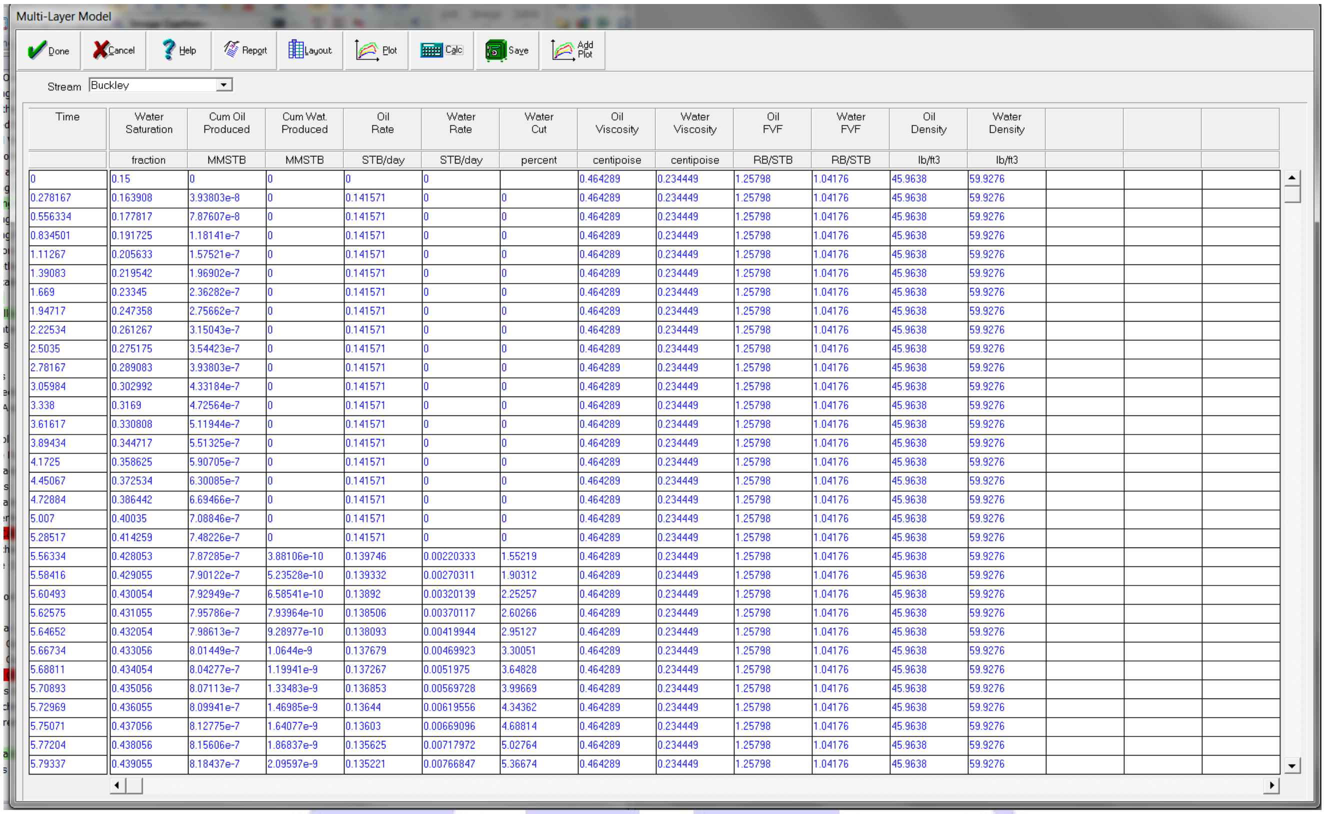
Enter the relevant information, and click the **Plot** button to check the quality and validity of the data.

➡ *Please note that relative permeabilities are always represented as functions of water saturation.*

2.9.6 Running a Calculation

To run a calculation, choose **Calculations|Run Calculation**.

A screen (as seen below) will appear:



Stream Buckley

Time	Water Saturation	Cum Oil Produced	Cum Wat. Produced	Oil Rate	Water Rate	Water Cut	Oil Viscosity	Water Viscosity	Oil FVF	Water FVF	Oil Density	Water Density
	fraction	MMSTB	MMSTB	STB/day	STB/day	percent	centipoise	centipoise	RB/STB	RB/STB	lb/ft3	lb/ft3
0	0.15	0	0	0	0		0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
0.278167	0.163908	3.93803e-8	0	0.141571	0	0	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
0.556334	0.177817	7.87607e-8	0	0.141571	0	0	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
0.834501	0.191725	1.18141e-7	0	0.141571	0	0	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
1.11267	0.205633	1.57521e-7	0	0.141571	0	0	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
1.39083	0.219542	1.96902e-7	0	0.141571	0	0	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
1.669	0.23345	2.36282e-7	0	0.141571	0	0	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
1.94717	0.247358	2.75662e-7	0	0.141571	0	0	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
2.22534	0.261267	3.15043e-7	0	0.141571	0	0	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
2.5035	0.275175	3.54423e-7	0	0.141571	0	0	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
2.78167	0.289083	3.93803e-7	0	0.141571	0	0	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
3.05984	0.302992	4.33184e-7	0	0.141571	0	0	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
3.338	0.3169	4.72564e-7	0	0.141571	0	0	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
3.61617	0.330808	5.11944e-7	0	0.141571	0	0	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
3.89434	0.344717	5.51325e-7	0	0.141571	0	0	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
4.1725	0.358625	5.90705e-7	0	0.141571	0	0	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
4.45067	0.372534	6.30085e-7	0	0.141571	0	0	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
4.72884	0.386442	6.69466e-7	0	0.141571	0	0	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
5.007	0.40035	7.08846e-7	0	0.141571	0	0	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
5.28517	0.414259	7.48226e-7	0	0.141571	0	0	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
5.56334	0.428053	7.87285e-7	3.88106e-10	0.139746	0.00220333	1.55219	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
5.58416	0.429055	7.90122e-7	5.23528e-10	0.139332	0.00270311	1.90312	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
5.60493	0.430054	7.92949e-7	6.58541e-10	0.13892	0.00320139	2.25257	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
5.62575	0.431055	7.95786e-7	7.93964e-10	0.138506	0.00370117	2.60266	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
5.64652	0.432054	7.98613e-7	9.28977e-10	0.138093	0.00419944	2.95127	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
5.66734	0.433056	8.01449e-7	1.0644e-9	0.137679	0.00469923	3.30051	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
5.68811	0.434054	8.04277e-7	1.19941e-9	0.137267	0.0051975	3.64828	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
5.70893	0.435056	8.07113e-7	1.33483e-9	0.136853	0.00569728	3.99669	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
5.72969	0.436055	8.09941e-7	1.46985e-9	0.13644	0.00619556	4.34362	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
5.75071	0.437056	8.12775e-7	1.64077e-9	0.13603	0.00669096	4.68814	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
5.77204	0.438056	8.15606e-7	1.86837e-9	0.135625	0.00717972	5.02764	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276
5.79337	0.439055	8.18437e-7	2.09597e-9	0.135221	0.00766847	5.36674	0.464289	0.234449	1.25798	1.04176	45.9638	59.9276

Click the **Calc** button to start a simulation run. The calculation can be stopped at any time by clicking the **Abort** button. At the end of the calculation, the calculated pseudo relative permeability curve is displayed.

Click on the **Plot** button to view the relative permeability curve.

The pseudo relative permeability curve that is calculated here can be used by the 1-D Model and Material Balance Tool. To do so:

- Calculate the pseudo relative permeability curve as described above.
- Select the other tool that is to be used - do not select File-New or File-Open at this point or the table will be lost.
- In the relative permeability dialogue for the other tool, select the **Copy** button and the pseudo relative permeability curve should appear in the list labelled as **Multi Layers – Reservoir**.

2.9.7 Fw/Fg Matching

The purpose behind this tool is to generate a set of Corey function parameters that will give the same fractional flows at the given saturations as were calculated by the multi-layer model..

The relative permeabilities can be generated for any stream that has been calculated in the Multi-layer calculation dialogue.

Choose the stream to regress on by selecting the stream in the item menu option.

In a Corey function, the relative permeability for the phase x is expressed as :

$$\mathrm{Krx} = \mathrm{Ex} * \left(\frac{\mathrm{Sx} - \mathrm{Srx}}{\mathrm{Smx} - \mathrm{Srx}} \right)^{\mathrm{nx}}$$

where :
Ex is the end point for the phase x,
nx the Corey Exponent,
Sx the phase saturation,
Srx the phase residual saturation and
Smx the phase maximum saturation.

The phase absolute permeability can then be expressed as :

$$\mathrm{Kx} = \mathrm{K} * \mathrm{Krx}$$

where :
K is the reservoir absolute permeability and
Krx the relative permeability of phase x.

For the purpose of clarity, the following detailed explanation describes the matching of the water fractional flow in an oil tank. The case of gas in an oil tank is identical with water replaced by gas.

MBALs first step is to calculate the points from the input stream - these are shown as points on the plot. For each stream point the Sw value is taken from the value calculated by the multi-layer calculation. The Fw value is calculated using the rates from the multi-layer calculation and the PVT properties. The water fractional flow can be expressed as :

$$Fw = \frac{Qw * Bw}{Qo * Bo + Qw * Bw}$$

where :
mx is the viscosity,
Qx the flow rate and
Bx the Formation volume factor of phase x.

The second step is to calculate the theoretical values - these are displayed as the solid line on the plot. As for the date points, the water saturations are taken from calculated stream. The Fw is calculated from the PVT properties and the current relative permeability curves using:

$$Fw = \frac{\dfrac{Kw}{\mu w}}{\dfrac{Kw}{\mu w} + \dfrac{Ko}{\mu o}}$$

Data points can be hidden from the regression by double clicking on the point to remove. A group of points can also be removed by drawing a rectangle around these points using the right mouse button. The data points weighting in the regression can also be changed using the same technique. Refer to Weighting of Regression Points for more information.

The breakthrough for the saturation that is displayed on the X axis is marked on the plot by a vertical blue line. This will be taken into account by the regression. The breakthrough value can be changed on the plot by simply double-clicking on the new position - the breakthrough should be redrawn at the new position.

Click on **Regression** to start the calculation. The program will display a set of Corey function parameters that best fits the data.

➲ These parameters represent the best mathematical fit for the data, insuring a continuity in the WC, GOR and WGR between calculation stream and forecast. This set of Corey function parameters will make sure that the fractional flow equations used in the material balance tool will reproduce as close as possible the fractional flow calculated by the multi-layer model

These parameters have to be considered as a group and the individual value of each parameter does not have a real meaning as, most of the time, the solution is not unique.

The set of parameters can be edited by selecting Parameters option from the plot menu.

This set of regressed parameters can be copied into the multi-layer data set by selecting the **Save** option from the plot menu.

2.10 Tight Gas Type Curve Tool

2.10.1 Background

This model was originally developed in response to the industry requirement to calculate the GIIP and perform forecasting calculations for transient gas reservoirs without resorting to numerical simulation.

It is commonly known that the method of material balance is only valid when the reservoir has developed fully into pseudo-steady state when average reservoir pressures can be estimated. In some tight gas reservoirs however, the period of interest may be during the transient period. So the basic assumption of material balance will lead to errors in the estimation of the gas in place and hence the forecasted volumes.The tight gas type curve tool can also be used to model ***coalbed methane*** (CBM).

In cases in which transience is of importance the 'Tight Gas Type Curve Tool' can be used, however, this calculation has some limitations:

Limitations of Tight Gas Model

The tight gas model (and all analytic well testing equations) are based on Darcy’s equations. These equations assume:

- a non-compressible fluid i.e. constant PVT for all pressures.
- For non-volatile oils the approximation is reasonable.
- For volatile oils and especially gases the approximation is rarely reasonable.

We can linearise the equations using pseudo pressure and pseudo time. For many cases this gives a reasonable solution but it is not perfect, especially if we have large drawdowns. In particular, the question of what representative pressure to use for the fluid when reservoir pressure is varying throughout the reservoir. For transient conditions even the rate of change of pressure throughout the reservoir is not constant.

The result of these approximations is that material balance is not always respected. This can lead to Gp > OGIP in predictions.

In MBAL IPM 8 we have improved the pseudo time calculations which has improved the accuracy in many cases. But it is still fundamentally an approximation.

Model Selection

As transient behaviour is being examined, reservoir geometry as well as size will need to be considered.

So the first step is to select a reservoir model. The tool currently supports two models:

- a well in the centre of a circular reservoir and
- a ***fractured*** well in the centre of a circular reservoir

The next step is history matching in which measured wellbore pressures are analysed to determine the size and permeability of the reservoir. Six different plots are provided for history matching depending on the method in use, despite the fact that different methods are available, they all achieve the same purpose - to estimate the reservoir permeability and size. However some plots work better than others depending on the nature and quality of the wellbore pressure data.

In IPM 8.0, broadly speaking three modifications have been made to the Tight Gas type curve calculation:

- Improvements in Pseudo-time calculations
- Calculation of FBHP from FWHP
- Wattenbarger Plot

Improvements in Pseudo-time calculations

It has been noted that the tight gas calculations do not obey material balance. This is due to the basic equations assuming constant PVT. This overcomes to some extent by using pseudo pressure and pseudo time. A manifestation of this problem is that we sometimes get overproduction (Gp > OGIP) during predictions. This happens particularly with high drawdown.

Although this has not been completely solved, the situation has been greatly improved by the use of an improved pseudo time. This does a more accurate integration by creating calculation steps in between those in the production history or the prediction.

This is a new option so that previous matches are not invalidated. But all new cases should use this option and it is now the default.

Calculation of FBHP from FWHP

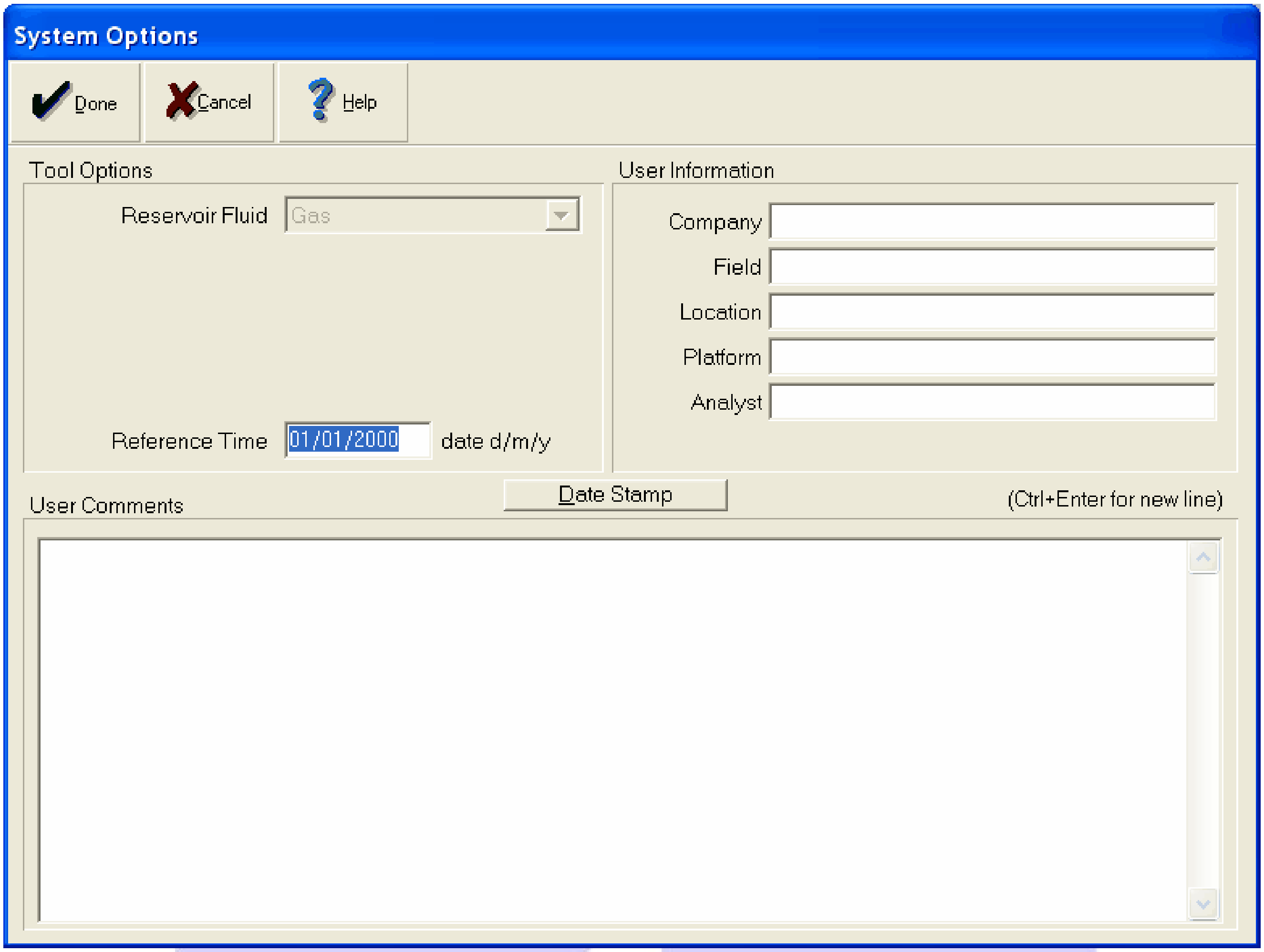
The user can now enter WHP instead of BHP and calculate BHP from the WHP and a lift curve. Since the lift curves are affected by water they will need to enter the water rates as well so a WGR can be calculated. Then we get the FBHP simply be performing a lookup from the lift curve.

Wattenbarger Plot

This is a history matching plot which estimates the OGIP. It main advantage is that it ignores any transient data so even if your skin, permeability, fracture length etc are unknown, you can still get the OGIP independently. It is basically the same as the Cartesian Plot used in classic welltest analysis but with superposition and pseudo time (Ref is SPE paper # 00084286.pdf).

2.10.2 Tight Gas Tool Options

The Tight Gas Tool is only valid for gas as the name suggests. The options therefore are defaulted to reflect this:


System Options
Done
Cancel
Help
Tool Options
User Information
Company
Field
Location
Platform
Analyst
User Comments
Date Stamp
(Ctrl+Enter for new line)

Reservoir Fluid: Gas

Reference Time: 01/01/2000 date d/m/y

Input Fields

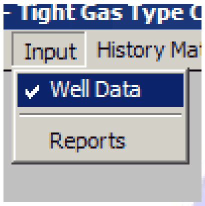
<table>
<tr>
<td>Reference date</td>
<td>The format that time data is displayed in MBAL can be of two types:
<table>
<tr><td>Date</td><td>A calendar date displayed in the format defined by Windows e.g. 23/12/2001 or 02/28/98</td></tr>
<tr><td>Time</td><td>A decimal number of days, weeks, months or years since a reference date</td></tr>
</table>
The format is selected for the time unit type in the Units dialogue.
If days, weeks, months or years (rather than date format) have been selected, this field allows entering the reference date.</td>
</tr>
</table>

User Information	The information for these fields is optional. The general details entered here provide the banner/header information that identify the reservoir in the reports and plots generated by the program
User Comments and Date Stamp	Space where a log of the updates or changes to the file can be stored. This comments box can also be used to exchange information between users. An unlimited amount of text is allowed. Press **Ctrl+Enter** to start a new paragraph. The comments box can be viewed by either dragging the scroll bar thumb or using the up and down directional arrow keys. The **Date Stamp** command adds the current date and time to the User Comments Box

The rest of the fields (User Information and User Comments) are the same as the 'Options' screen in the other tools of **MBAL**.

2.10.3 Input

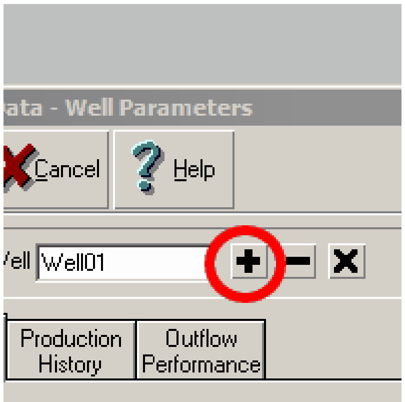
As the 'Tight Gas Too'l is focused on analysing bottom hole pressure data from individual wells, the only option available here is to enter the well data or perform reporting.

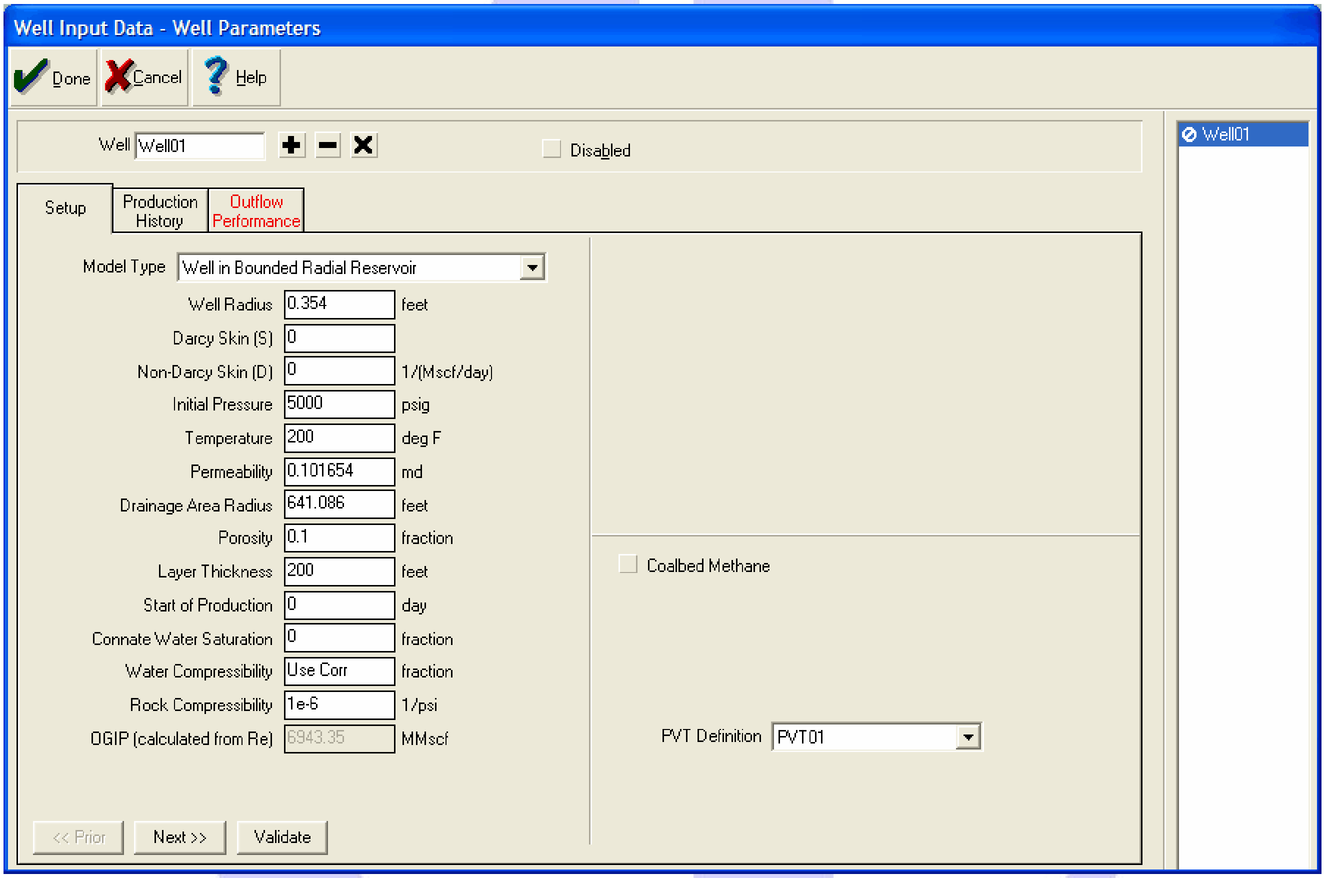


In the input screen, the user will be able to define the necessary parameters to perform the history matching and carry out a prediction.

2.10.3.1 Well Data: conventional reservoir

This option allows the user to enter the data needed to perform the analysis on a well by well basis. When this window is entered for the first time, a well needs to be created as carried out when using material balance well. This can be done using the '+' button shown below:


ata - Well Parameters
Cancel
Help
ell
Well01
Production History
Outflow Performance


Well Input Data - Well Parameters
Done
Cancel
Help
Setup
Production History
Outflow Performance
<< Prior
Next >>
Validate
Well01

Well: Well01

☐ Disabled

Model Type	Well in Bounded Radial Reservoir	
Well Radius	0.354	feet
Darcy Skin (S)	0	
Non-Darcy Skin (D)	0	1/(Mscf/day)
Initial Pressure	5000	psig
Temperature	200	deg F
Permeability	0.101654	md
Drainage Area Radius	641.086	feet
Porosity	0.1	fraction
Layer Thickness	200	feet
Start of Production	0	day
Connate Water Saturation	0	fraction
Water Compressibility	Use Corr	fraction
Rock Compressibility	1e-6	1/psi
OGIP (calculated from Re)	6943.35	MMscf

☐ Coalbed Methane

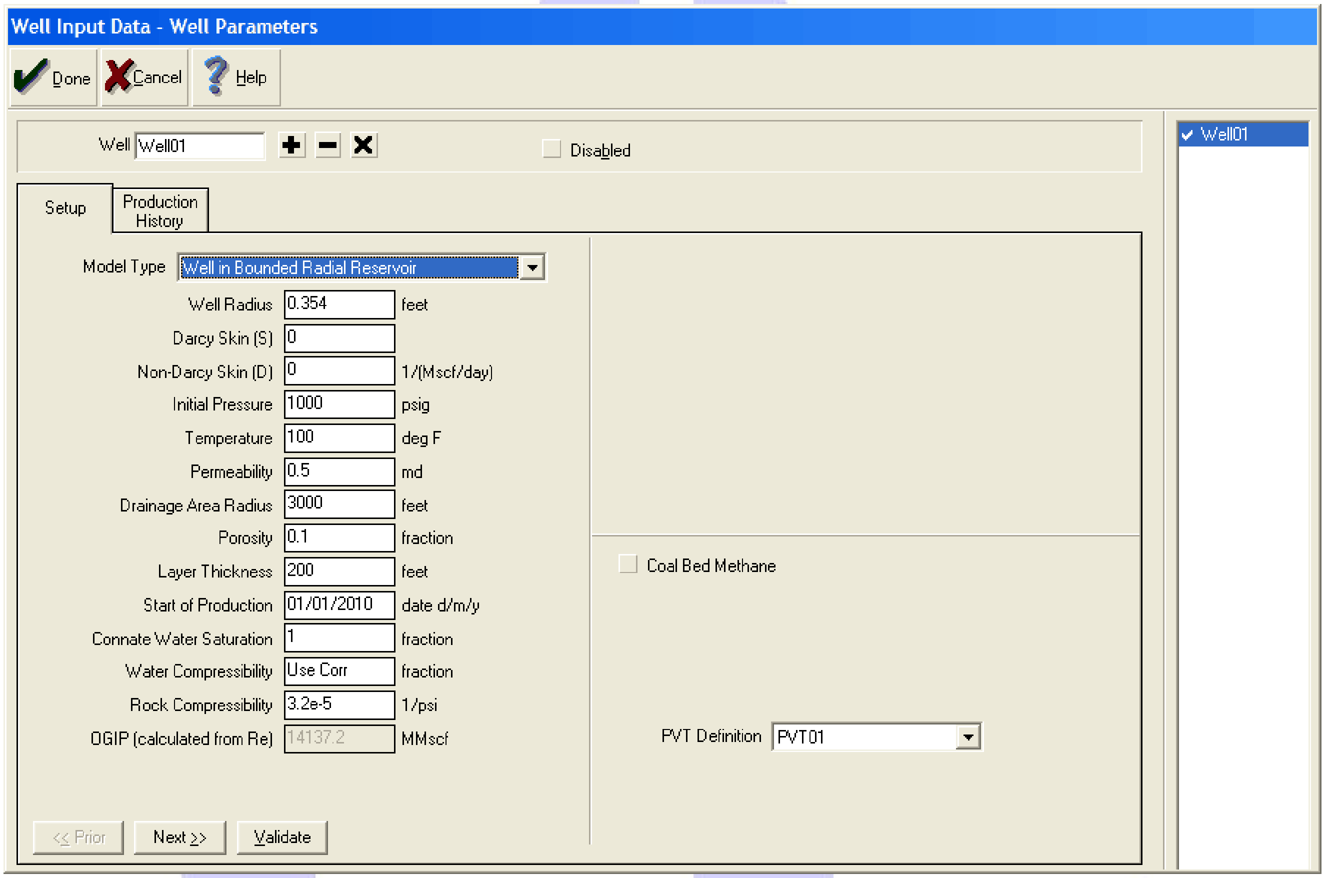
PVT Definition: PVT01

Three screens are available here as can be seen from the screenshot above.

The 'Setup Screen' allows the user to enter the information relating to the reservoir and inflow, whereas the second screen allows the user to enter the production history on which the transient analysis will be done. The final screen allows the entry of VLP Curves (lift curves) that can be used to translate the wellhead pressure constraints into bottomhole pressures during the prediction.

NOTE: The Outflow Performance tab (VLP) is only visible during the prediction stage and will not be used for history matching.

2.10.3.1.1 Tight Gas Well Data Setup



Well Well01

☐ Disabled

Model Type Well in Bounded Radial Reservoir

Well Radius	0.354	feet
Darcy Skin (S)	0	
Non-Darcy Skin (D)	0	1/(Mscf/day)
Initial Pressure	1000	psig
Temperature	100	deg F
Permeability	0.5	md
Drainage Area Radius	3000	feet
Porosity	0.1	fraction
Layer Thickness	200	feet
Start of Production	01/01/2010	date d/m/y
Connate Water Saturation	1	fraction
Water Compressibility	Use Corr	fraction
Rock Compressibility	3.2e-5	1/psi
OGIP (calculated from Re)	14137.2	MMscf

☐ Coal Bed Methane

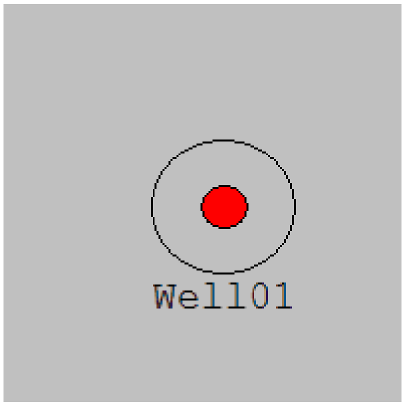
PVT Definition PVT01

There are currently two models available:

- well in bounded radial reservoir and
- fractured well in bounded radial reservoir.

The reservoir can be a conventional one where the gas is stored in the pore volume or a coal reservoir where the gas molecules adhere to the surface of the coal.

For the latter case, check the option "Coal Bed Methane" and then click the 'Langmuir Isotherm' button to enter the required data.



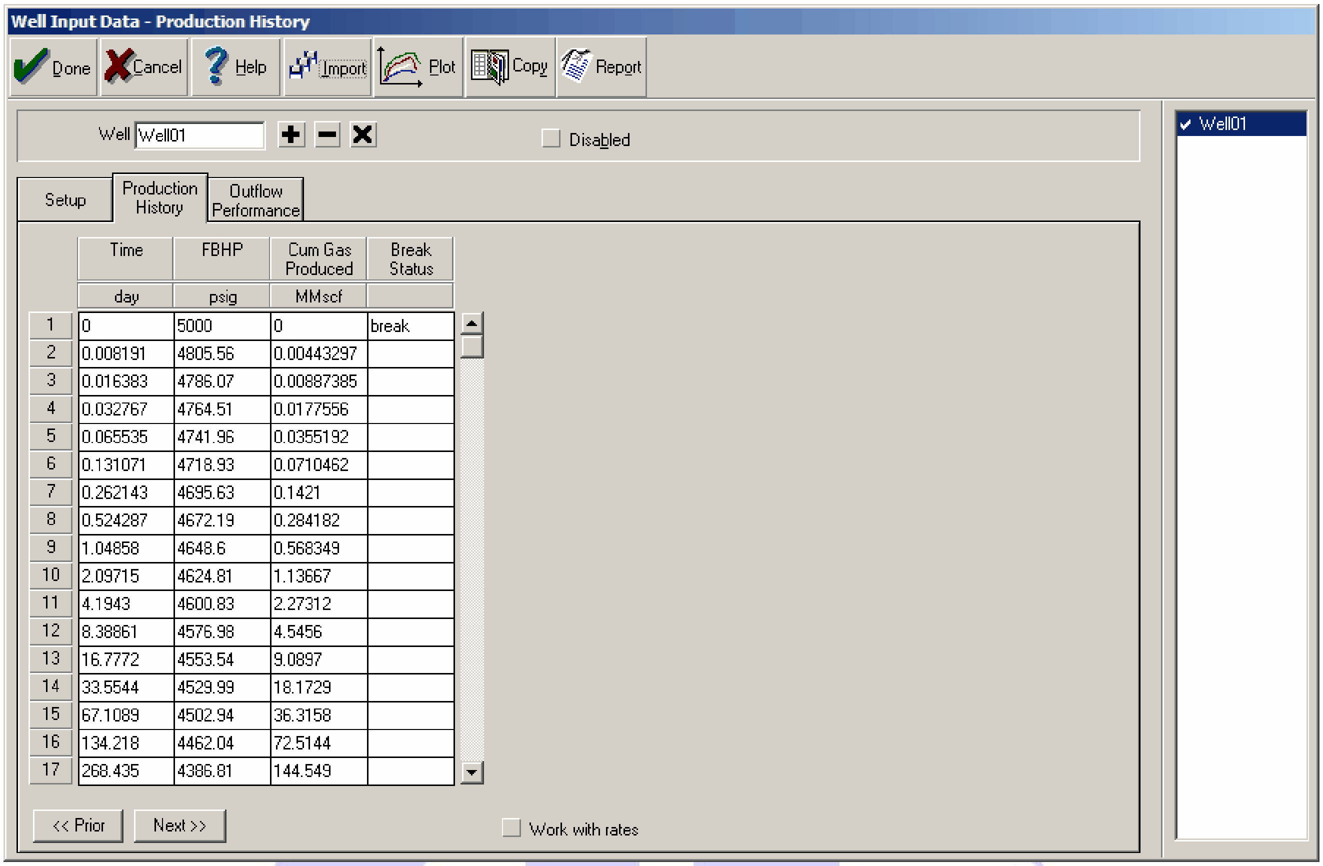
The Darcy and non-Darcy Skins relate to the transient inflow equation as S and D factors respectively:

$$m(P_i) - m(P_{wf}) = \frac{1442T}{kh}\left[\sum_{j=1}^{n}(Q_j - Q_{j-1})P_D(t_{dn} - t_{dj-1}) + SQ_n + DQ_n^2\right]$$

The drainage area radius entry is an estimate at this stage. This will be a result of the type curve analysis and the estimate will serve as a starting point from which the analysis will continue.

2.10.3.1.2 Tight Gas Well Data Production History

Either the gas rate or cumulative produced gas can be entered with the FBHP, the time over which the information was obtained is also necessary:


Well Input Data - Production History
Done
Cancel
Help
Import
Plot
Copy
Report
+
−
X
Setup
Production History
Outflow Performance
<< Prior
Next >>
Well01

Well: Well01

☐ Disabled

	Time	FBHP	Cum Gas Produced	Break Status
	day	psig	MMscf	
1	0	5000	0	break
2	0.008191	4805.56	0.00443297	
3	0.016383	4786.07	0.00887385	
4	0.032767	4764.51	0.0177556	
5	0.065535	4741.96	0.0355192	
6	0.131071	4718.93	0.0710462	
7	0.262143	4695.63	0.1421	
8	0.524287	4672.19	0.284182	
9	1.04858	4648.6	0.568349	
10	2.09715	4624.81	1.13667	
11	4.1943	4600.83	2.27312	
12	8.38861	4576.98	4.5456	
13	16.7772	4553.54	9.0897	
14	33.5544	4529.99	18.1729	
15	67.1089	4502.94	36.3158	
16	134.218	4462.04	72.5144	
17	268.435	4386.81	144.549	

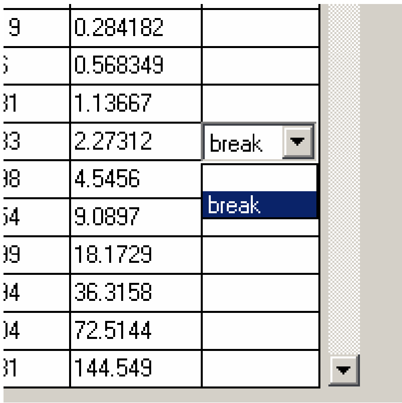
☐ Work with rates

The rest of the options in the table are the same as in the 'Material Balance' tool. Traditionally, the easiest way to enter the data into the table is via the copy/paste functionality of the table (from Excel). The import button can also be used which allows transfer of data from an ASCII file.

Just as in the 'Material Balance' tool history, care should be taken to ensure that the units in the table in Excel match the units of **MBAL**. If the units are different, then the units used in **MBAL** can be changed within the 'Units Window'.

The 'Break Status' can be changed by clicking inside the row break window, which will drop down a menu for selecting the status as 'Break' or 'Empty'.

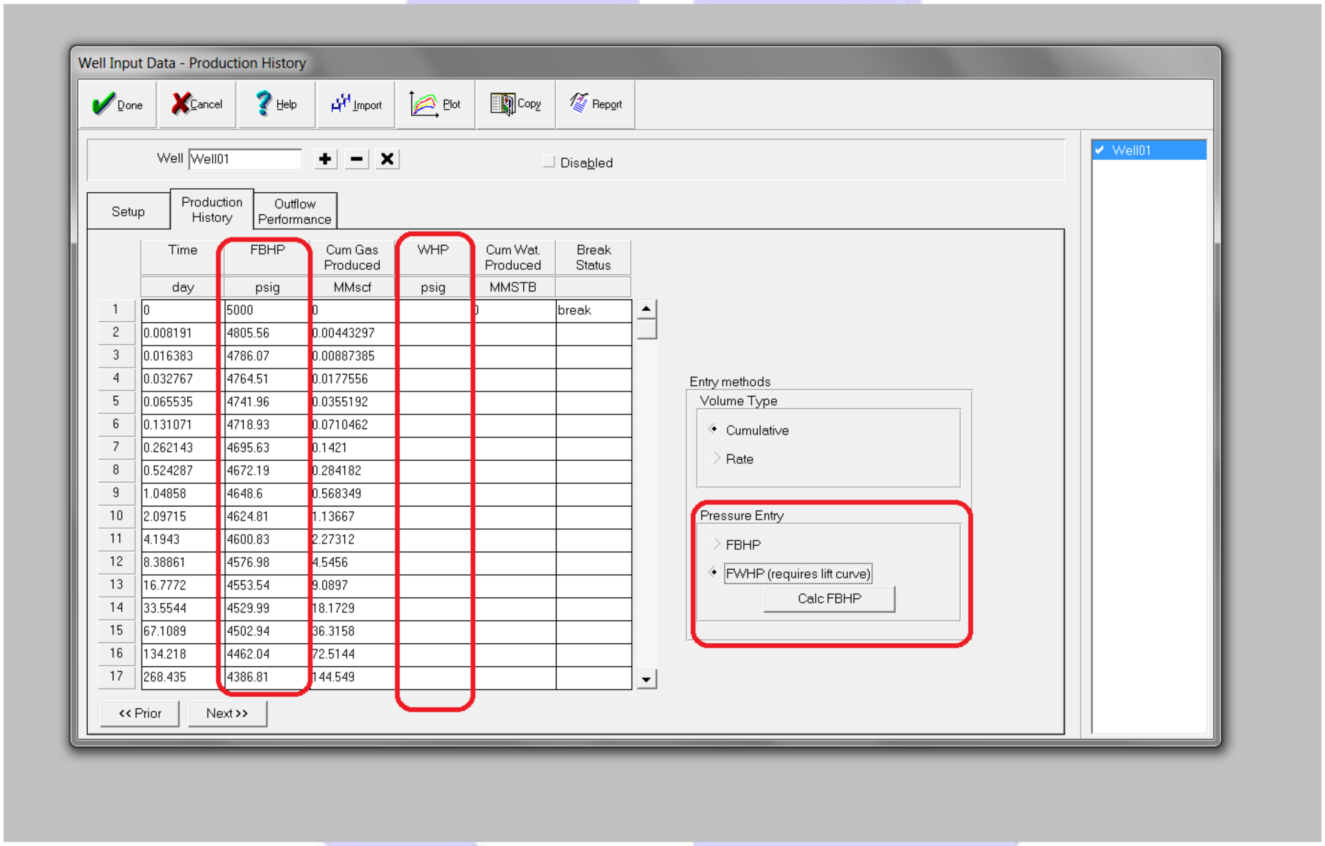
This allows the user to manually define any intervals or shut-in periods during the production time.



9	0.284182	
5	0.568349	
31	1.13667	
33	2.27312	break
38	4.5456	
54	9.0897	break
39	18.1729	
34	36.3158	
04	72.5144	
31	144.549	

New in IPM 8.0

The flowing bottomhole pressures can be calculated from the WHP and a lift curve. Entering the WHP data, the lift curve would be used to generate the corresponding BHPs.



Well Input Data - Production History

Done
Cancel
Help
Import
Plot
Copy
Report
Setup
Production History
Outflow Performance
<< Prior
Next >>
Calc FBHP

Well: Well01 ☐ Disabled

☑ Well01

	Time	FBHP	Cum Gas Produced	WHP	Cum Wat. Produced	Break Status
	day	psig	MMscf	psig	MMSTB	
1	0	5000	0		0	break
2	0.008191	4805.56	0.00443297			
3	0.016383	4786.07	0.00887385			
4	0.032767	4764.51	0.0177556			
5	0.065535	4741.96	0.0355192			
6	0.131071	4718.93	0.0710462			
7	0.262143	4695.63	0.1421			
8	0.524287	4672.19	0.284182			
9	1.04858	4648.6	0.568349			
10	2.09715	4624.81	1.13667			
11	4.1943	4600.83	2.27312			
12	8.38861	4576.98	4.5456			
13	16.7772	4553.54	9.0897			
14	33.5544	4529.99	18.1729			
15	67.1089	4502.94	36.3158			
16	134.218	4462.04	72.5144			
17	268.435	4386.81	144.549			

Entry methods

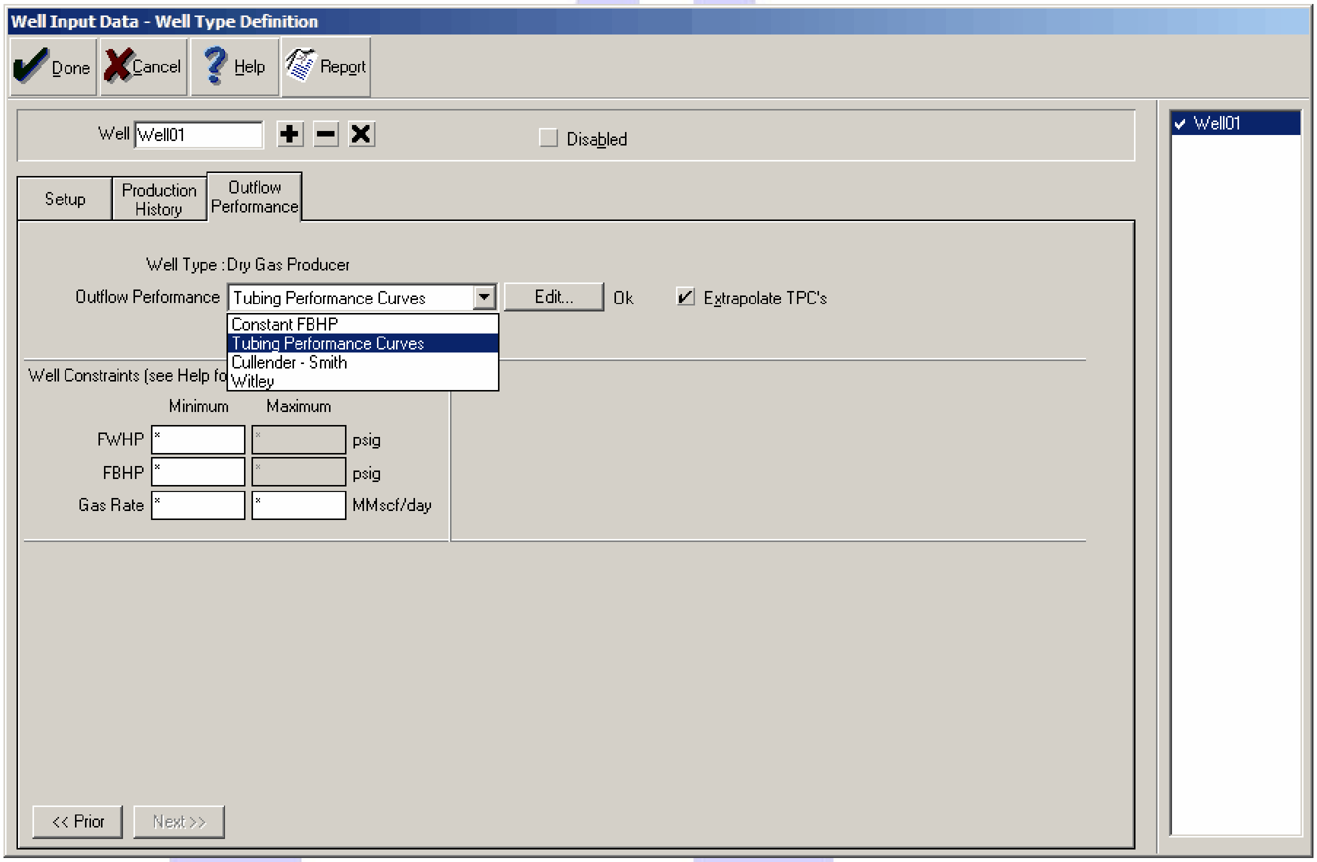
Volume Type
● Cumulative
○ Rate

Pressure Entry
○ FBHP
● FWHP (requires lift curve)

2.10.3.1.3 Tight Gas Well Data Outflow Performance

The outflow performance information is used during the prediction phase to relate the well head pressure to a bottom hole pressure.

As with other screens in this tool, the options are the same as those present in the material balance tool:


Well Input Data - Well Type Definition
Done
Cancel
Help
Report
Setup
Production History
Outflow Performance
Edit...
Ok
Constant FBHP
Tubing Performance Curves
Cullender - Smith
Witley
Well Constraints (see Help fo
Minimum
Maximum
FWHP
FBHP
Gas Rate
psig
psig
MMscf/day
<< Prior
Next >>

Well: Well01

☐ Disabled

Well Type : Dry Gas Producer

Outflow Performance: Tubing Performance Curves

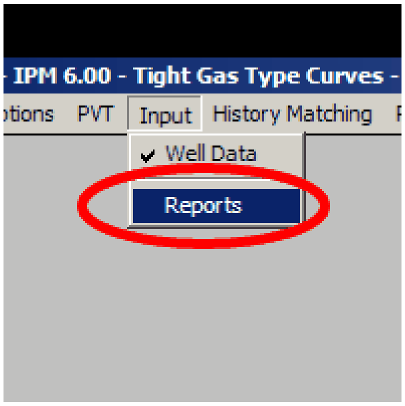
☑ Extrapolate TPC's

✓ Well01

The option which most accurately represents the pressure drops is the the 'Tubing Performance Curves' which can be generated using PROSPER. The other methods can be used to obtain some indication of the bottomhole pressure, they will not however be as rigorous as the lift curves.

2.10.3.2Tight Gas Input Data Report

The reporting section of the input data is the second option accessed from the 'Input' menu and as the name suggests, it can be used to generate reports of the options and input data in the model:

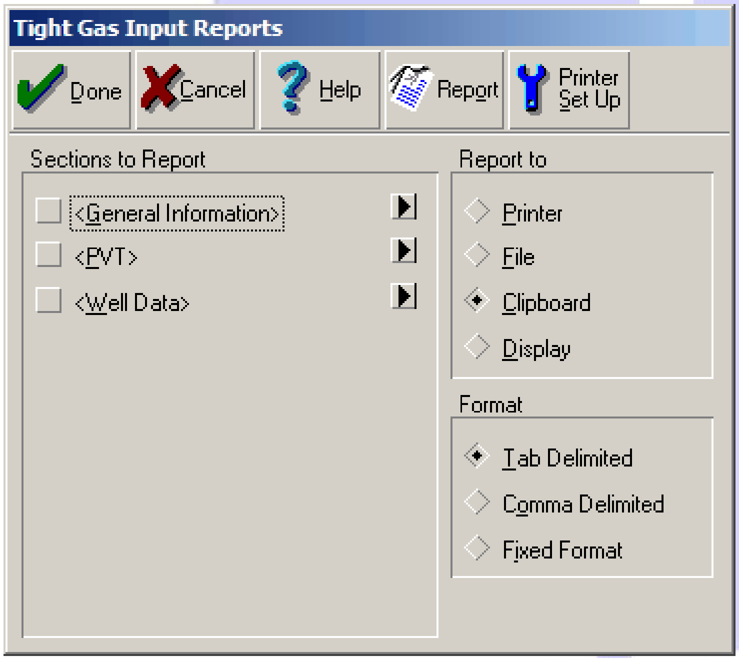

IPM 6.00 - Tight Gas Type Curves -
ptions PVT Input History Matching F
Well Data
Reports

2.10.3.2.1 Tight Gas Well Input Data Report

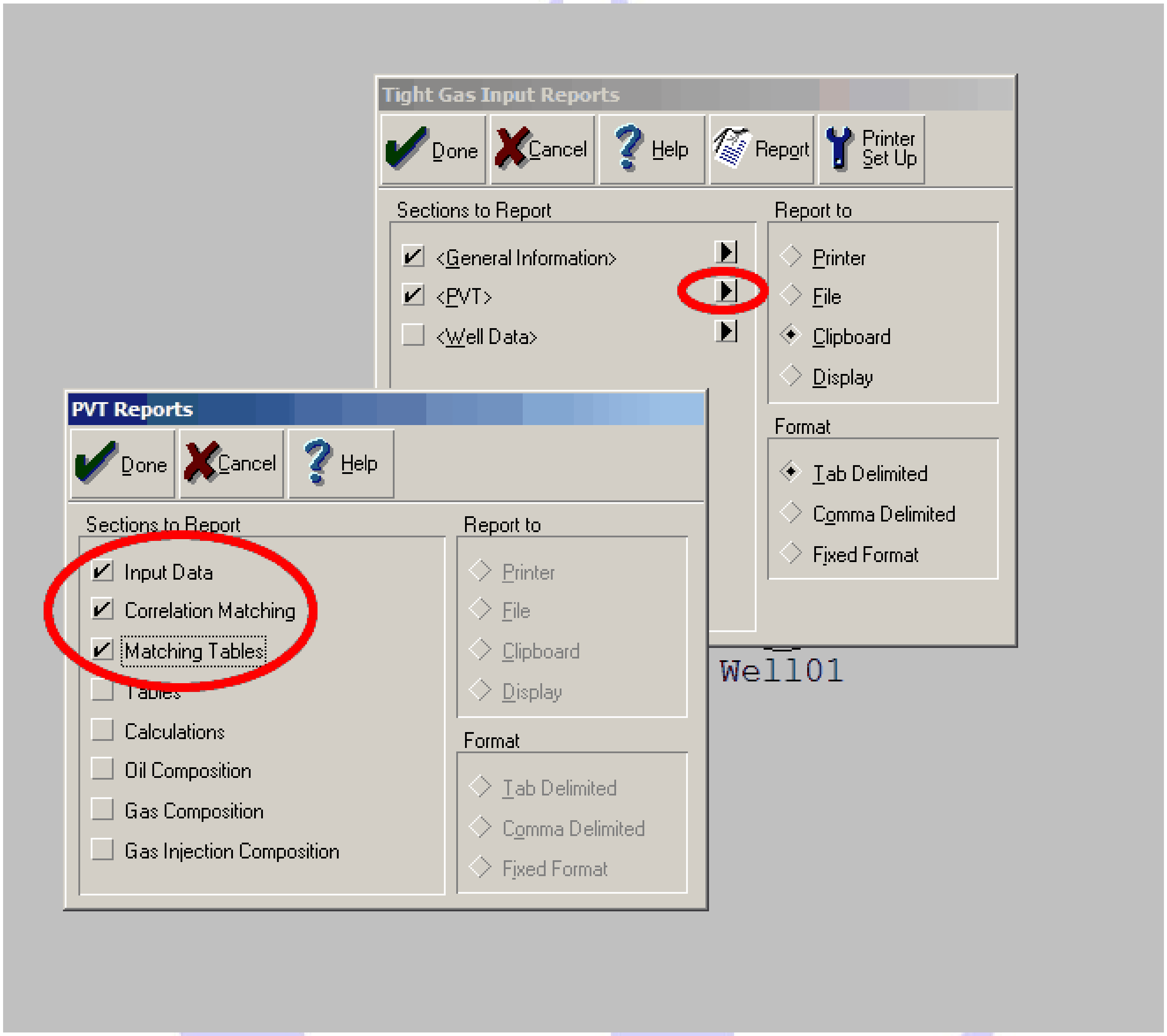
The reporting of this particular tool follows the same rules as the reporting in the Material Balance tool and consists of three main areas of selection. These relate to General Information, PVT and Well Data as shown in the screen below:

The method for reporting the data in the model, remains the same as for the 'Material Balance' tool.

The report consists of three main sections (General Information, PVT and Well Data), of which one, or all three can be reported:


Tight Gas Input Reports
Done
Cancel
Help
Report
Printer Set Up
Sections to Report
☐ <General Information>
☐ <PVT>
☐ <Well Data>
Report to
○ Printer
○ File
● Clipboard
○ Display
Format
● Tab Delimited
○ Comma Delimited
○ Fixed Format

To create a report, select the section (of the three options) of interest; another screen will then appear requiring definition of which information within the defined section is to be reported:


Tight Gas Input Reports
Done
Cancel
Help
Report
Printer Set Up
PVT Reports
Done
Cancel
Help
Well01

Tight Gas Input Reports

Sections to Report
☑ <General Information>
☑ <PVT>
☐ <Well Data>

Report to
○ Printer
○ File
● Clipboard
○ Display

Format
● Tab Delimited
○ Comma Delimited
○ Fixed Format

PVT Reports

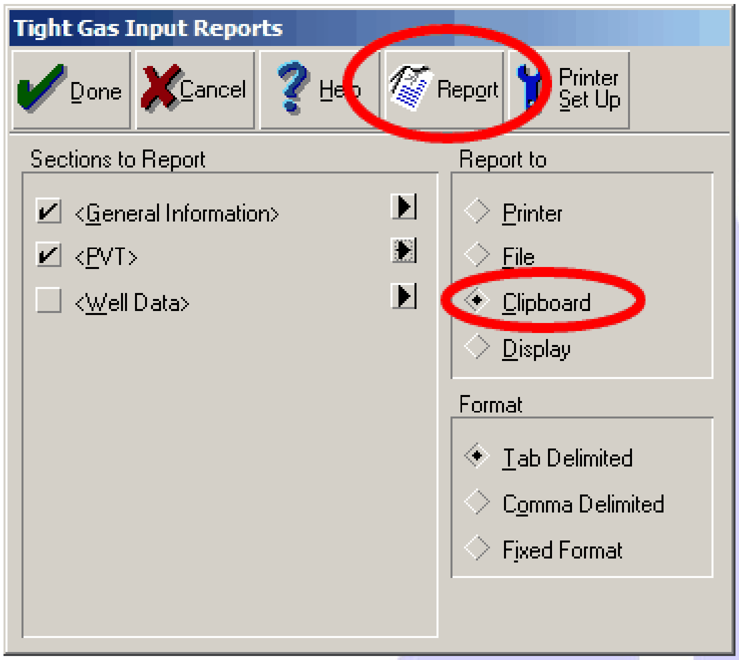
Sections to Report
☑ Input Data
☑ Correlation Matching
☑ Matching Tables
☐ Tables
☐ Calculations
☐ Oil Composition
☐ Gas Composition
☐ Gas Injection Composition

Report to
○ Printer
○ File
○ Clipboard
○ Display

Format
○ Tab Delimited
○ Comma Delimited
○ Fixed Format

Having selected the required information, it can now be transferred. The following example shows how to transfer data across the to a word document with the use of the clipboard;

Selecting 'Clipboard' and 'Report':



Sections to Report

☑ <General Information>

☑ <PVT>

☐ <Well Data>

Report to

○ Printer

○ File

● Clipboard

○ Display

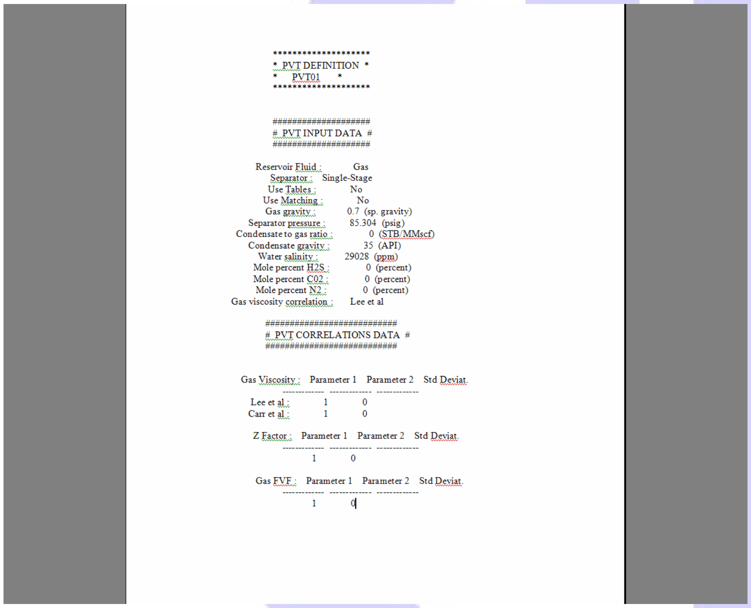
Format

● Tab Delimited

○ Comma Delimited

○ Fixed Format

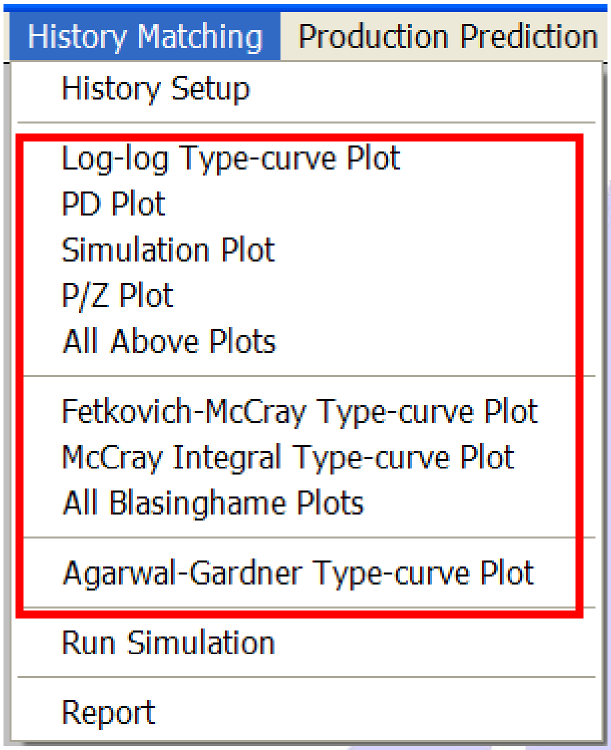
The Word document can be opened and the information can be pasted:



```
*********************
*  PVT DEFINITION  *
*     PVT01      *
*********************


####################
#  PVT INPUT DATA  #
####################

     Reservoir Fluid :        Gas
         Separator :   Single-Stage
        Use Tables :          No
      Use Matching :           No
       Gas gravity :        0.7  (sp. gravity)
  Separator pressure :       85.304  (psig)
Condensate to gas ratio :          0  (STB/MMscf)
  Condensate gravity :          35  (API)
     Water salinity :       29028  (ppm)
   Mole percent H2S :          0  (percent)
   Mole percent C02 :          0  (percent)
    Mole percent N2 :          0  (percent)
Gas viscosity correlation :     Lee et al

###########################
#  PVT CORRELATIONS DATA  #
###########################


  Gas Viscosity :   Parameter 1   Parameter 2   Std Deviat.
                ------------  ------------  ------------
   Lee et al :           1            0
   Carr et al :          1            0

     Z Factor :   Parameter 1   Parameter 2   Std Deviat.
                ------------  ------------  ------------
                        1            0

      Gas FVF :   Parameter 1   Parameter 2   Std Deviat.
                ------------  ------------  ------------
                        1            0
```

2.10.4 History Matching

The history matching can be carried out in a variety of ways:


History Matching
Production Prediction
History Setup
Log-log Type-curve Plot
PD Plot
Simulation Plot
P/Z Plot
All Above Plots
Fetkovich-McCray Type-curve Plot
McCray Integral Type-curve Plot
All Blasinghame Plots
Agarwal-Gardner Type-curve Plot
Run Simulation
Report

There are two main blocks of plots in the screen above, the first relating to the classical Type Curve Plot. The second block relates to the Blasinghame Plots.

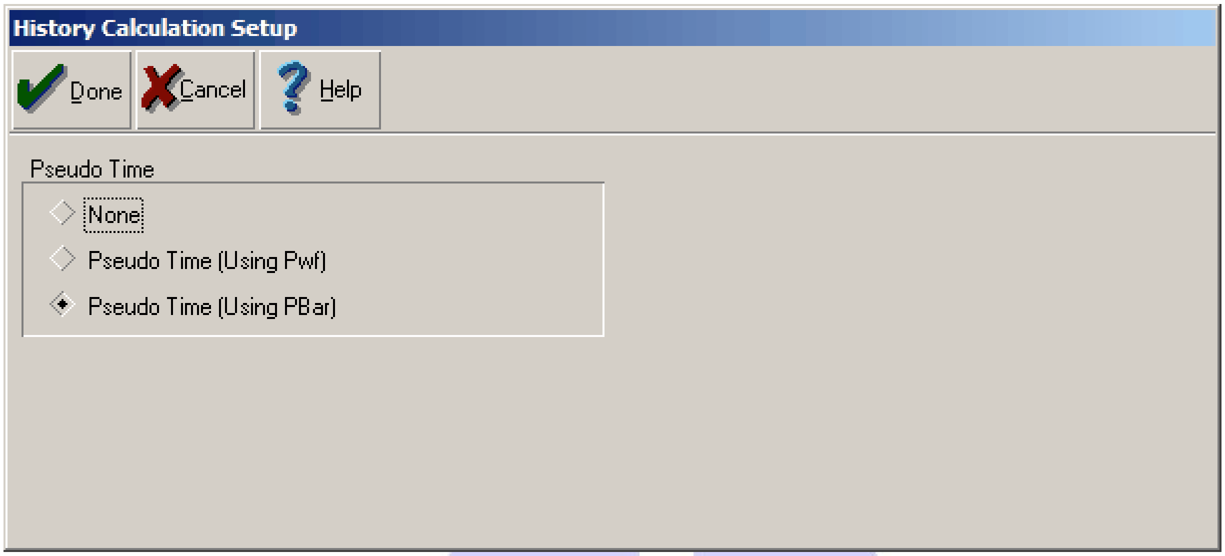
Each of the above plots has an option to perform an automatic regression. The regression algorithm is the same in all plots regardless of the presentation of the data.

The regression adjusts the permeability and drainage radius to best match the input wellbore pressures and the theoretical wellbore pressures calculated from the full superposition function:

$$m(P_i) - m(P_{wf}) = \frac{1442T}{kh}\left[\sum_{j=1}^{n}(Q_j - Q_{j-1})P_D(t_{dn} - t_{dj-1}) + SQ_n + DQ_n^2\right]$$

2.10.4.1 Tight Gas History Setup

The options in the history setup relate to the choice of Pseudo Time:



History Calculation Setup

Pseudo Time

○ None

○ Pseudo Time (Using Pwf)

● Pseudo Time (Using PBar)

2.10.4.2Tight Gas History Type Curve Plot

Log-log Type Curve Matching

This is based on the traditional well-testing plot of log time vs log delta pressure. The following modifications are made:

- Pseudo Pressure is used instead of pressure to model the effect of changing fluid properties.
- To remove the effects of changing rates, superposition time Vs rate normalised delta pseudo pressure is used. This will convert the data into the equivalent constant rate data at least up to the end of the transient period. Once pseudo-steady state has been reached, the conversion will not be rigorous as the response is no longer logarithmic.
- The rate normalised delta pseudo pressure is corrected to account for non-Darcy skin.

So we plot the derivative of

$$\frac{m(P_i)-m(P_{wfn})}{Qn} - FQ_n vs \sum_{j=1}^{n} \frac{Q_j - Q_{j-1}}{Q_n} \log(t_n - t_{j-1})$$

If we have a reservoir in the centre of a circle, the data should show a horizontal line during the early transient period. When the reservoir response develops into pseudo-steady state the data should become a straight line of unit slope.

The theoretical response is displayed as a type curve. The type curve is displayed as Pd vs Tda so that we have a single type curve for all of the reservoir sizes. The data can then be matched against the type curve.

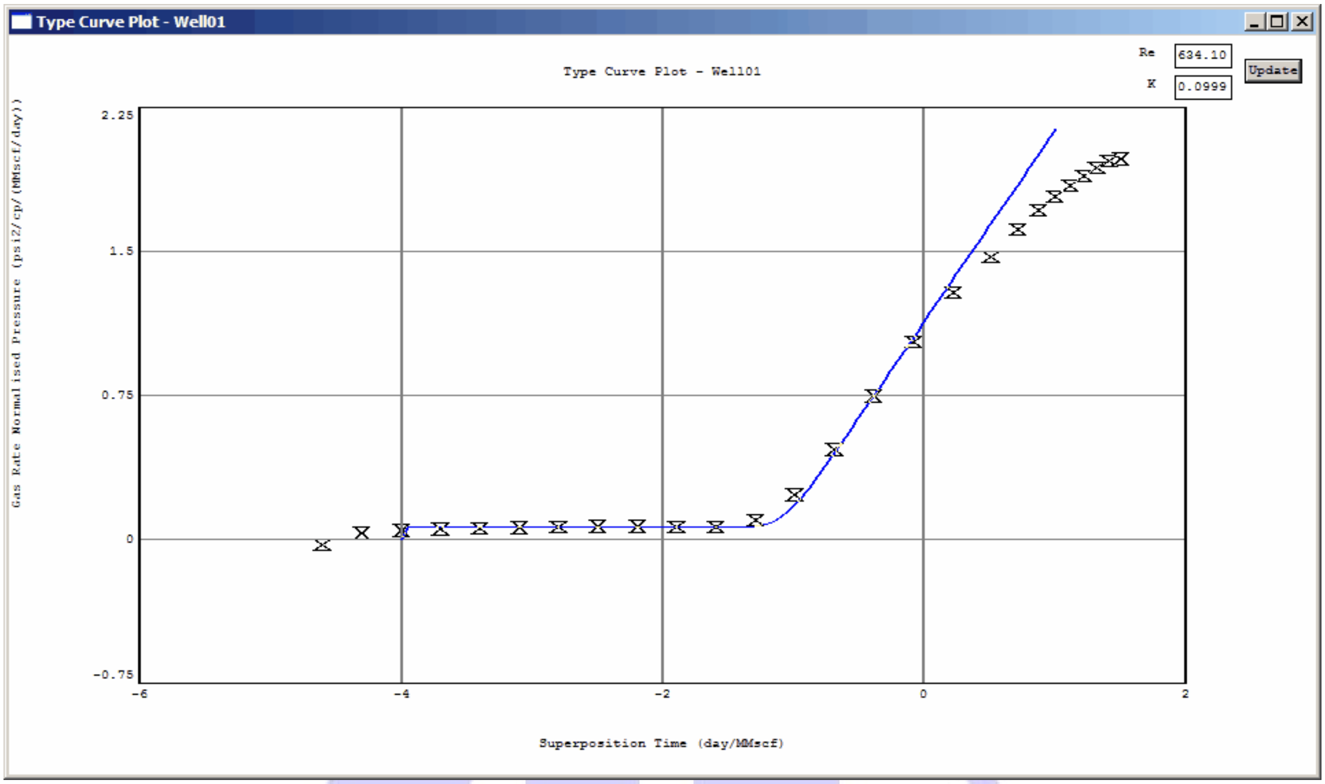
The vertical match will give the permeability from

$$K = \frac{Y_{match} \; P_{sc} T_{res}}{0.00001987 \; h T_{sc}}$$

The horizontal match will give the drainage area from

$$A = \frac{0.006336 \; K}{\phi \mu_g C_t X_{match}}$$

On the plot itself, if the 'Shift' button on the keyboard is held down and at the same time the left mouse button is clicked, the data is released from the screen and can be moved around. This can be done so as to fit the type curve as closely as possible. Shifting the plot up or down changes the K and shifting it left or right changes the Re numbers.


Type Curve Plot - Well01
Type Curve Plot - Well01
Update
Gas Rate Normalised Pressure (psi2/cp/(MMscf/day))
2.25
1.5
0.75
0
-0.75
-6
-4
-2
0
2
Superposition Time (day/MMscf)

Re 634.10

K 0.0999

2.10.4.3 Tight Gas History PD Plot

In this plot, the data is displayed in a form similar to the Log-log type curve plot. The difference is that when superposition time is in use, the full Pd response rather than the log approximation is utilised:

$$\frac{m(P_i)-m(P_{wfn})}{Qn} - FQ_n vs \sum_{j=1}^{n}\frac{Q_j - Q_{j-1}}{Q_n}Pd(t_n - t_{j-1}, R_d)$$

This means that the permeability and drainage area affect the plotted data so if the reservoir is close to the selected model then when the correct K and drainage area are entered, all of the data should lie on a horizontal line. The advantage of this is that the superposition is so rigorous in removing the effects of changing rates all of the data (once the correct K and drainage area have been selected) making it particularly useful when there are large changes in rate during the production period.

The procedure in this plot is to change the K and drainage area until a straight line has been obtained.

2.10.4.4Tight Gas History Simulation Plot

The data on this plot is shown simply as wellbore pressure vs time. A line is also drawn on this plot showing the simulated response for the current estimate of permeability and drainage area.

The simulated response is calculated from the full superposition model :

$$m(P_i) - m(P_{wf}) = \frac{1442T}{kh}\left[\sum_{j=1}^{n}\left(Q_j - Q_{j-1}\right)P_D\left(t_{dn} - t_{dj-1}\right) + SQ_n + DQ_n^2\right]$$

The drainage radius and permeability can be manually changed to match the data. The plot is particularly useful for matching late time data.

2.10.4.5Tight Gas History P/Z Plot

For transient reservoirs, wellbore pressures as opposed to average reservoir pressures are available so a normal P/Z plot cannot be analysed. However we can extrapolate the average reservoir pressure from the wellbore pressures. This is done by using the full superposition model above to extrapolate the Pwf to the stabilised pressure at infinite time.

The estimated average reservoir pressures are then plotted on normal P/Z plot.

In all the above plots, one can also choose to use: normal time, pseudo time based on wellbore pressure or pseudo time based on average reservoir pressure. The pseudo time functions are used to model the effects of changing viscosity and compressibility with pressure. If pseudo time based on average reservoir pressure is used, we calculate the average reservoir pressure using the P/Z relationship and the current estimate of OGIP based on the current estimate of drainage area. This means that the pseudo time will be recalculated every time that the drainage radius is recalculated.

2.10.4.6Tight Gas History Fetkovich-McCray Plot

This plot is taken from the paper “Decline-Curve Analysis Using Type Curves-Analysis of Gas Well Production Data” by J.C. Palacio and T.A. Blasinghame (SPE 25909) which explains the method. It is derived from decline curve theory but extended to use analytic reservoir models. It uses a simplified superposition time and is particularly useful for poor quality data.

One important difference between this plot and the above plots is that the pseudo pressure used is normalised pseudo pressure rather than the standard definition of pseudo pressure.

The data is plotted with the following transformation on the X axis:

$$\bar{t}_a = \frac{\mu_{gi} C_{ti}}{Q_g} \int_0^t \frac{Q_g}{\mu_g(\bar{p}) C_t(\bar{p})} dt$$

In the original paper the pressure in the above equation of pseudo time was always taken as the average reservoir pressure, however it has also been implemented with the other options of no pseudo time and pseudo time based on Pwf in which case, Pbar with Pi and Pwf are replaced respectively.

Also in the original paper a method was developed to estimate the OGIP from the data which is used to calculate the average reservoir pressure for use in the pseudo time. However it has been found that an initial very rough estimate of drainage area (and hence the OGIP) is sufficient to give a reasonable first match. With the new drainage area, the pseudo time is recalculated and a second (or at most third match) will give an unchanging result. So it was not felt that reproducing the method of initial estimate of OGIP would be of added beneficial use.

The data is plotted in two different forms on the Y axis:

$$Q_d = \frac{Q_g}{m(P_i) - m(P_{wfn})}$$

$$Q_{di} = \frac{1}{\bar{t}_a} \int_0^{t_a} \frac{Q_g}{m(P_i) - m(P_{wfn})} d\bar{t}_a$$

Type-curves are generated for several values of Rd.

The vertical match gives the permeability from:

$$K = \frac{141.2 B_{gi} \mu_{gi} (\ln(R_d) - 0.5)}{h Y_{match}}$$

The horizontal match gives the OGIP from:

$$OGIP = \frac{hK}{141.2 X_{match} C_t B_{gi} \mu_{gi} \left(\ln\left(R_d\right) - 0.5 \right)}$$

The drainage area can then be calculated from the OGIP.

The dimensionless variables in this plot are:

$$Q_{Dd} = \frac{141.2 B_i \mu_i}{kh} \frac{Q}{P_i - P_{wfn}} \left[\ln\left(\frac{r_e}{r_w} \right) - 0.5 \right]$$

$$t_{Dd} = 0.00633 \frac{k}{\phi \mu_i C_{ti} r_w^2} \frac{1}{\frac{1}{2}\left[\frac{r_e^2}{r_w^2} - 1 \right]\left[\ln\left(\frac{r_e}{r_w} - \frac{1}{2} \right) \right]} t$$

2.10.4.7Tight Gas History McCray Integral Plot

This plot is the same as the Fetkovich-McCray Type-curve plot above except that the two quantities plotted on the Y axes are:

$$Q_{di} = \frac{1}{\bar{t}_a} \int_0^{t_a} \frac{Q_g}{m\left(P_i\right) - m\left(P_{wfn}\right)} d\bar{t}_a$$

$$Q_{did} = \bar{t}_a \frac{d}{d\bar{t}_a} \left[\frac{1}{\bar{t}_a} \int_0^{t_a} \frac{Q_g}{P_i - P_{wfn}} d\bar{t}_a \right]$$

2.10.4.8Tight Gas History Simulation

This feature allows wellbore pressures to be generated from the input history rates.

2.10.4.9Tight Gas History Simulation Plot

This feature allows the generation of wellbore pressures from the input history rates. The same method is carried out as for the 'Simulate Plot' above.

2.10.4.10 Tight Gas History Report

Reporting options are the same as in the 'Material Balance' tool.

2.10.4.11 Tight Gas History Agarwal-Gardner

This method is new to **IPM** version 7.

This history matching method is based upon the following paper:

Agarwal, Gardner, Kelinsteiber and Fussel, 'Analyzing Well Production Using Combined-Type-Curve and Decline-Curve Analysis Concepts.'

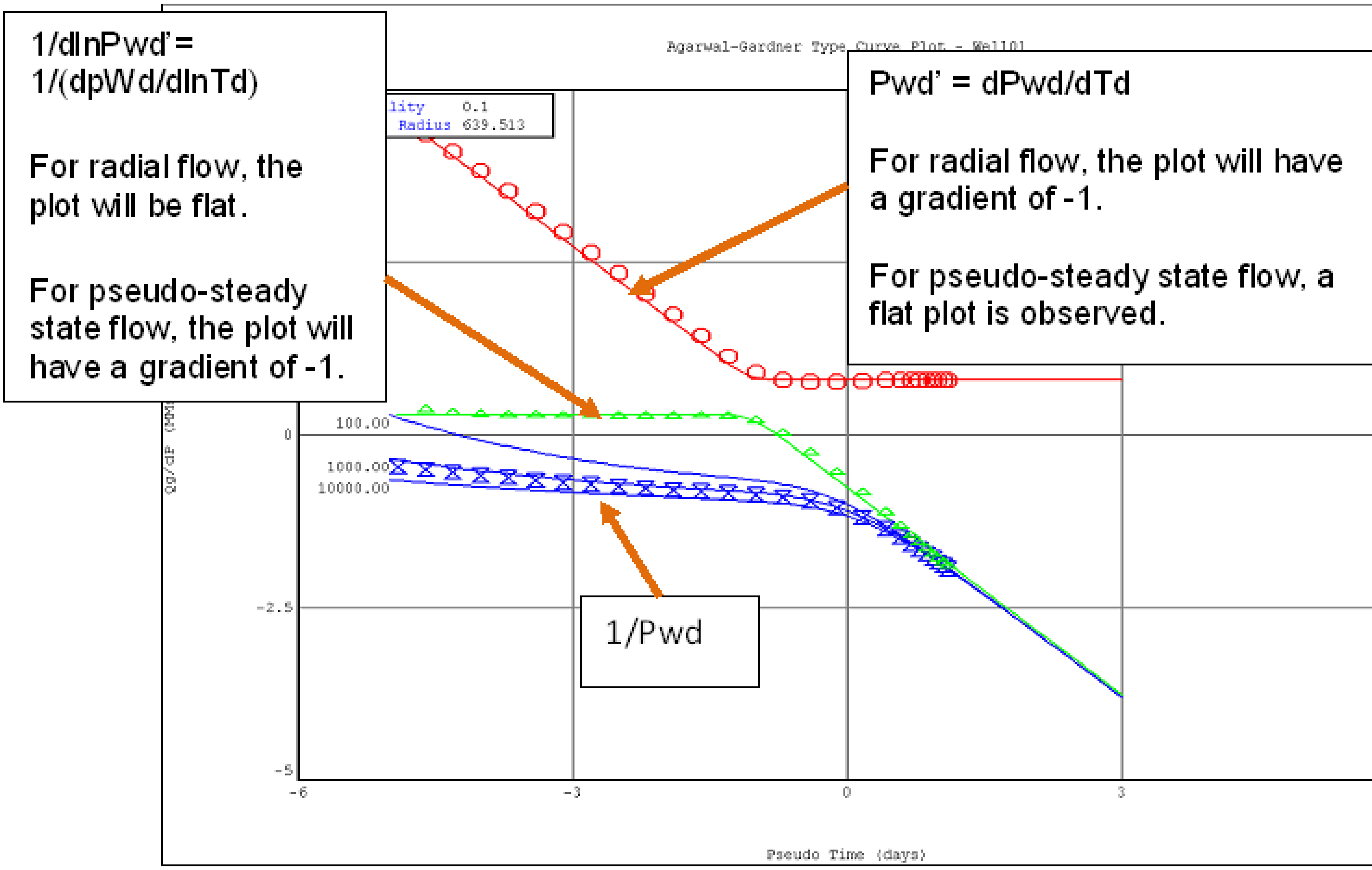
This method is applied to transient systems, for which measurable reservoir pressures would be unavailable, so wellbore pressures would instead be required.

The resulting plot shows three forms of dimensionless pressure plotted on the y-axis:

- 1/Pwd
- 1/dlnPwd' = 1/(dPwd/dlnTd)
- Pwd' = dPwd/dTd

Where Pwd = (k.h.dm(p))/(1422.T.Q)

When carrying out a match on the plot; the vertical match defines the permeability while the match along the horizontal axis defines the distance to the boundary.



1/dlnPwd' = 1/(dpWd/dlnTd)

For radial flow, the plot will be flat.

For pseudo-steady state flow, the plot will have a gradient of -1.

Pwd' = dPwd/dTd

For radial flow, the plot will have a gradient of -1.

For pseudo-steady state flow, a flat plot is observed.

1/Pwd

Due to the different match point which the Pwd' plot has with respect to the other plots, attempting to match all three at the same time could become very complex. To overcome this issue, it is possible to match them individually:

Selecting, 'Match On,' from the plot screen, allows each plot to be selected and matched individually.

The time function in use is the same as the Blasingham type-curve as defined in 'Tight Gas History Fetkovich-McCray Plot.'

Type curves showing fractured wells are also available.

2.10.4.12 How disabled points are handled in tight gas history matching

Log log plot

Pd Plot

Does not plot disabled points. Also disabled points are not included in superposition. So disabled points are discarded before we do anything. So acts as if disabled points do not exist or have been deleted.

Simulation Plot

Disabled points are plotted. Simulation is done ignoring the disabled points. So they are ignored EXCEPT for plotting of history data.

Regression

Ignores disabled points completely, including in superposition. So acts as if disabled points do not exist or have been deleted.

P/Z plot

Ignores disabled points completely. So acts as if disabled points do not exist or have been deleted. This includes the best line fit.

Blasinghame Plots

Ignores disabled points completely, including in superposition. So acts as if disabled points do not exist or have been deleted.

Agarwal-Gardner

Ignores disabled points completely, including in superposition. So acts as if disabled points do not exist or have been deleted.

2.10.5 Tight Gas Prediction

The prediction option works in a similar manner to the material balance prediction. However there are important differences.

In material balance the rates are calculated from a pseudo-steady state inflow performance. This inflow is driven by the reservoir pressure.

In the tight gas modelling, the rates are generated from the a transient IPR. This inflow is driven by the rate history and the reservoir model i.e. permeability and drainage radius.

The 'Tight Gas' model does not actually need the average reservoir pressure (apart from for pseudo time based on average reservoir pressure).

The full superposition equation is:

$$m(P_i) - m(P_{wf}) = \sum_{j=1}^{n} (Q_j - Q_{j-1}) P_D (t_{dn} - t_{dj-1})$$

This can be re-arranged as:

$$m(P_i) - m(P_{wf}) = Q_n P_D (t_{dn} - t_{dj-1}) + \sum_{j=1}^{n-1} (Q_j - Q_{j-1}) P_D (t_{dn} - t_{dj-1}) - Q_{n-1} P_D (t_{dn} - t_{dj-1})$$

This results in a relationship at any time between the delta pressure and the current rate Qn which is the only necessary information for a transient IPR. For each time, the rate can be calculated using the transient IPR and the lift curve. As each rate is calculated, the time and rate is added to the production history.

The above equations omit skin and non-Darcy skin for clarity but these are included in the model.

Real time, pseudo time based on Pwf or pseudo time based on average reservoir pressure can be used in the prediction. If necessary, the average reservoir pressure is calculated using: the P/Z relationship, the cumulative rates and the OGIP.

Limitations

The model can account for water vapour (condensed water). This will need to be activated on the PVT input screen.

It is however a single phase gas model because does not account for the effect of free water water production on the reservoir pressure.

The effect of water production on the well performance is accounted for. Water production can be entered as look-up tables in form of Water-Gas-Ratio as function of time / pressure or cumulative production (see WGR from lookup table on the outflow performance sheet).

The model is designed to handle dry and wet gas reservoirs. It is not designed to handle retrograde condensate reservoirs.

Important Note on Entry of Rates

In transient theory the convention of rate entry is that the rate reported at a particular time is the rate during the step prior to that time. This is the convention shown in the equations above.

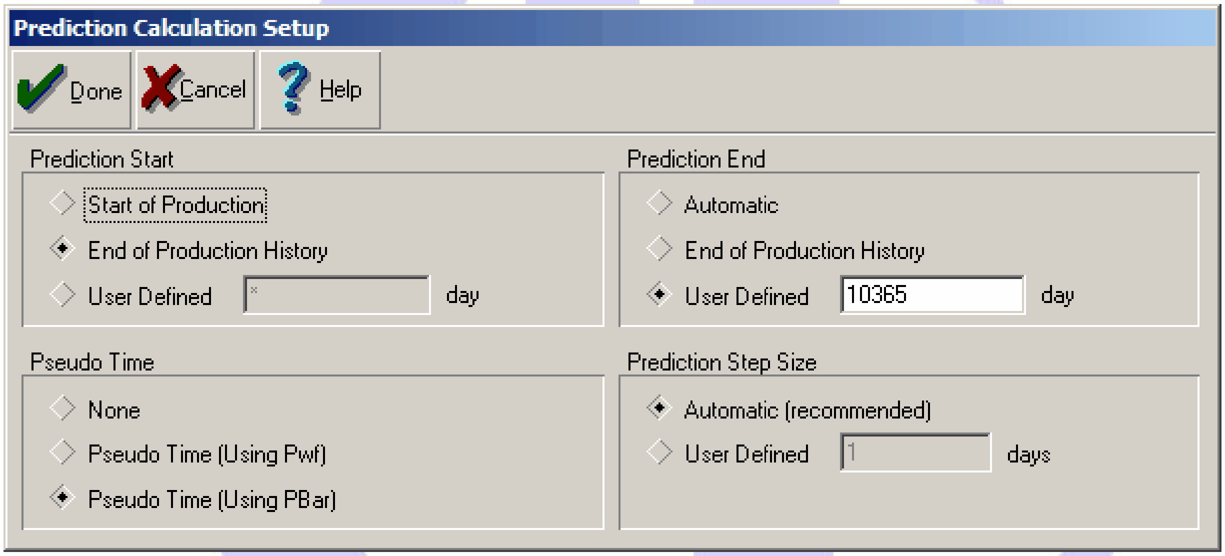
However the **IPM** programs use a different convention. The rate reported at a particular time is the rate during the step following that time.

A decision had to be made whether to keep to the normal transient definition or change it to the **IPM** convention.

It was decided that is was better to keep rate definitions across the **IPM** software consistent, so the in use convention is as defined above.

2.10.5.1Tight Gas Prediction Setup

In the prediction setup, options relating to the beginning and end of history can be selected as well as the pseudo time formulation:



Prediction Calculation Setup

Prediction Start
- ○ Start of Production
- ● End of Production History
- ○ User Defined day

Prediction End
- ○ Automatic
- ○ End of Production History
- ● User Defined 10365 day

Pseudo Time
- ○ None
- ○ Pseudo Time (Using Pwf)
- ● Pseudo Time (Using PBar)

Prediction Step Size
- ● Automatic (recommended)
- ○ User Defined 1 days

The prediction step size represents the time-step for the prediction run.

There are three options available for the pseudo time formulation.

General transient theory assumes that the product of viscosity and compressibility remain constant with respect to the change in pressure. This is the assumption when using the Normal

Time method. Thus when using the 'Pseudo Time' set to 'NONE', the viscosity and compressibility are assumed to be constant with respect to the change in pressure.

Since this is a simplifying assumption, MBAL (when working with the Tight Gas Tool) allows the user to select the Pseudo Time methodologies. The Pseudo Time is a normalised function of time that takes into account the changes in the viscosity and compressibility over time (due to the changes in pressure)

$$t_s = \mu_i C_{ti} \int_0^t \frac{dt}{\mu C_t}$$

The viscosity and compressibility itself must be calculated at a certain pressure. This is where the two further options are provided.

Selecting the "Pseudo Time (Using Pwf)" method will mean that the viscosity and compressibility are calculated at the Pwf. Selecting "Pseudo Time (Using Pbar)" will calculate the above mentioned properties at average reservoir pressure.

In the case of a transient system, the pressure changes in gas are significant in the reservoir. Using the Pwf method for the computation may not provide the best estimate of the pseudo time function. This is why the Pwf method is not a recommended option. For cases where the FBHP are significantly less than the reservoir pressure (very big draw downs), the Pseudo Time (Using Pbar) formulation may provide better results.

The Pbar function, which is the suggested approach, however leads to another question, where is the average pressure defined in a tight gas system. This is where the tight gas tool in MBAL uses the Material Balance approach in calculating the reservoir pressure.

Our experience of comparing results of MBAL and reservoir simulators indicates that pseudo time based on average reservoir pressure works most accurately when analysing production data. A number of tight gas systems with production history have been modelled in MBAL using the Pbar approach.

The decision on which method to use is best taken by the engineer performing the analysis.

2.10.5.2Tight Gas Prediction Constraints

In this screen the constraints relating to the production need to be entered. If a rate constraint is entered, the program will automatically raise the WHP in order to honour the constraint.

2.10.5.3Tight Gas Prediction

Selecting the "Calculate" button will run the prediction.

2.10.5.4Tight Gas Prediction Plot

The results can be seen in a graphical form, which uses the same layout as the 'Material Balance' tool.

2.10.5.5Tight Gas Prediction Report

Reporting any information for the tight gs model follows the same steps as for reporting material balance information.

2.11 Streamlines

2.11.1 Technical Background

Stream Lines

One of the investigations reservoir engineers typically perform relates to the determination of water breakthrough time and evolution of water cuts which is especially important for water flood systems.

Material balance models can be used to perform history matching, but have limited applicability in water cut prediction when history is not available.

Numerical simulation models can be used to track the evolution of the water front and data can also be used to match MBAL pseudo-rel perms to perform predictions.

In cases where history data is not available, MBAL models can be used with analogue rel perms or PV vs depth functions for water evolution. Streamline models can also be used in place of (or with) a full numerical simulator to provide a quick way of finding out breakthrough times and water cut evolution

Objectives

The Streamline module in MBAL provides a quick 2-D reservoir simulation to estimate:-

- Sweep Efficiencies
- Producer well fractional flows

for a set pattern of water injectors and oil producers.

This is not intended to replace a reservoir simulator, rather it allows quick analysis of different well patterns and their effect on the recovery.

The tool currently models a rectangular reservoir with a combination of no-flow or constant pressure (aquifer) boundaries. Other assumptions are that the PVT is constant and the streamlines calculated do not change position with time.

2.11.1.1 Methods and Equations

The basic calculation principles are as follows:-

- Generate image wells to model boundaries.
- Calculate the velocity field by doing time simulation
- Streamlines progress from the injectors to the producers over time
- Once a streamline reaches a producer, we would see the water cut increasing. The more streamlines reach the producers, the higher the water cut would be.
- Track the progression of water along the stream tubes with time.

Image wells

Image wells are setup to model the boundaries. The traditional method of images requires wells on either side of the boundary to produce a zero rate at the boundary. With this method, it is possible to end up with a very large number of image wells when modeling a rectangular reservoir. Instead we create a set of virtual wells around the reservoir.

For this, a set of flux points along the boundaries are created and solved for the virtual well rates to give potentials at these points to ensure a zero rate between the points i.e. a no-flow boundary. If there exists a constant pressure boundary then we calculate potentials to give the required rate across the boundary.

This involves forming a set of simultaneous equations with Qi (rate at image wells) as the variable. It is clearly difficult to describe such a complex set of equations but it can be explained in terms of a simple case.

Consider one image well (subscript i) and one real well (subscript r). We define two flux points along the boundary. We draw a line between the two flux points and find the midpoint. We then draw a line through this point but perpendicular to the line between the flux points with the same length. This other line then forms a symetrical cross with the line between the flux points. The points at the ends of this new line are called subscript ib & sb.

Now we know the potential of any point due to any well is proportional to:-

Qlog(dist)

So the flux between two points will be the difference between the two potentials. So the flux due to the real well say is:-

Qr[log((xib-xr)**2 + (yib-yr)**2)] - Qr[log((xsb-xr)**2 + (ysb-yr)**2)]

or

$$Q_r.log\left(\frac{(\mathrm{xib}-\mathrm{xr}) ** 2\ +\ (\mathrm{yib}-\mathrm{yr}) ** 2)}{(\mathrm{xsb}-\mathrm{xr}) ** 2\ +\ (\mathrm{ysb}-\mathrm{yr}) ** 2)}\right)$$

since log x/y = log x - log y
And similarly the flux between the two points due to the image well will be:-

$$Q_i.log\left(\frac{(\mathrm{xib}-\mathrm{xi}) ** 2\ +\ (\mathrm{yib}-\mathrm{yi}) ** 2)}{(\mathrm{xsb}-\mathrm{xi}) ** 2\ +\ (\mathrm{ysb}-\mathrm{yi}) ** 2)}\right)$$

But we want the flux between the two points to be zero so we need whatever flux is caused by the real well to be opposite and equal to the flux due to the image well. So we simply solve Qi so that the two terms above are equal.

For the real cases we have an equation for each pair of flux points.
The LHS is the flux due to the image wells and has all of the Qis as the variables.
The RHS is the total flux due to the real wells. If the boundary is an aquifer it also includes the flux required to make it a constant pressure boundary rather than no flow.

Aquifer Wells

If we have a constant pressure (aquifer) boundary we also create a number of aquifer wells which act like injectors. These are spaced equally along the aquifer boundary. Each aquifer has one stream line whereas each real injector has several (depending on the injection rate).

Streamlines

We then calculate the streamlines from each real injector and aquifer well. This is done by calculating the velocity vector which is the derivative of the potential due to all the wells with respect to distance. i.e.

$$dx/dt = CONSTN *sum(i=well) \frac{(Xi - X)*Qi}{(Xi-X)**2 + kx/ky*(Yi-Y)**2}$$

The streamline is terminated when it reaches a producer.

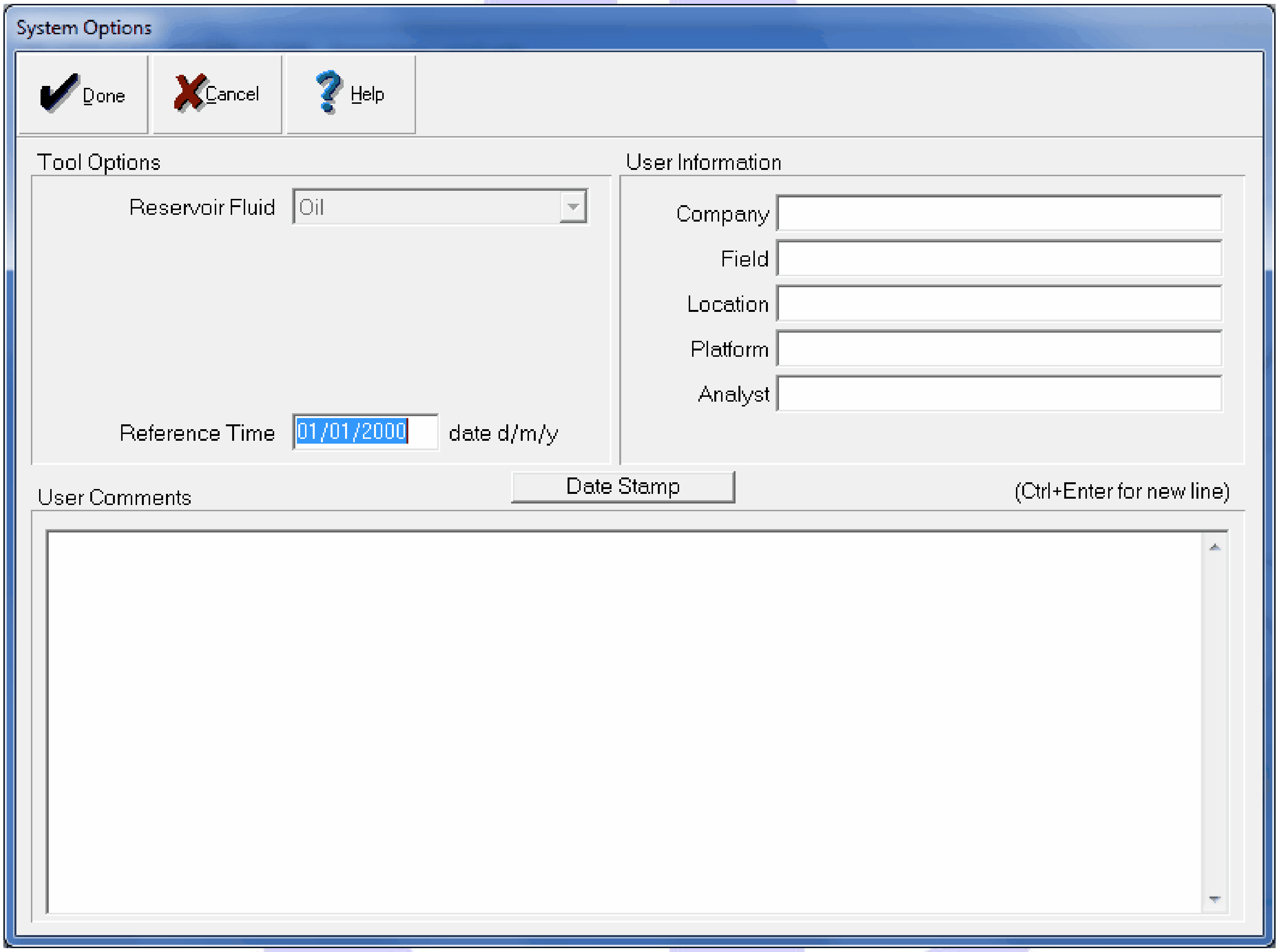
Volume Calculations

An equal proportion of the injection at each well passes along each streamline. The amount of liquid that enters each streamline is immediately produced at the producer well. Until the streamline reaches the producer well, the production is all oil. After the streamline reaches the producer, the producer will produce all water. Since different streamlines will reach the producer wells at different times then the water cut at the producer will only increase gradually.

Once we have all the streamlines accounted for we can calculate the recovery and hence the sweep efficiency.

2.11.2 Tool options

For streamlines, only a reference time is required within the options section:


System Options
Done
Cancel
Help
Tool Options
User Information
Company
Field
Location
Platform
Analyst
User Comments
Date Stamp
(Ctrl+Enter for new line)

Reservoir Fluid: Oil

Reference Time: 01/01/2000 date d/m/y

2.11.3 Input data

Input data for streamlines includes: PVT, Geometry, Tank parameters, Well position data and Calculation times

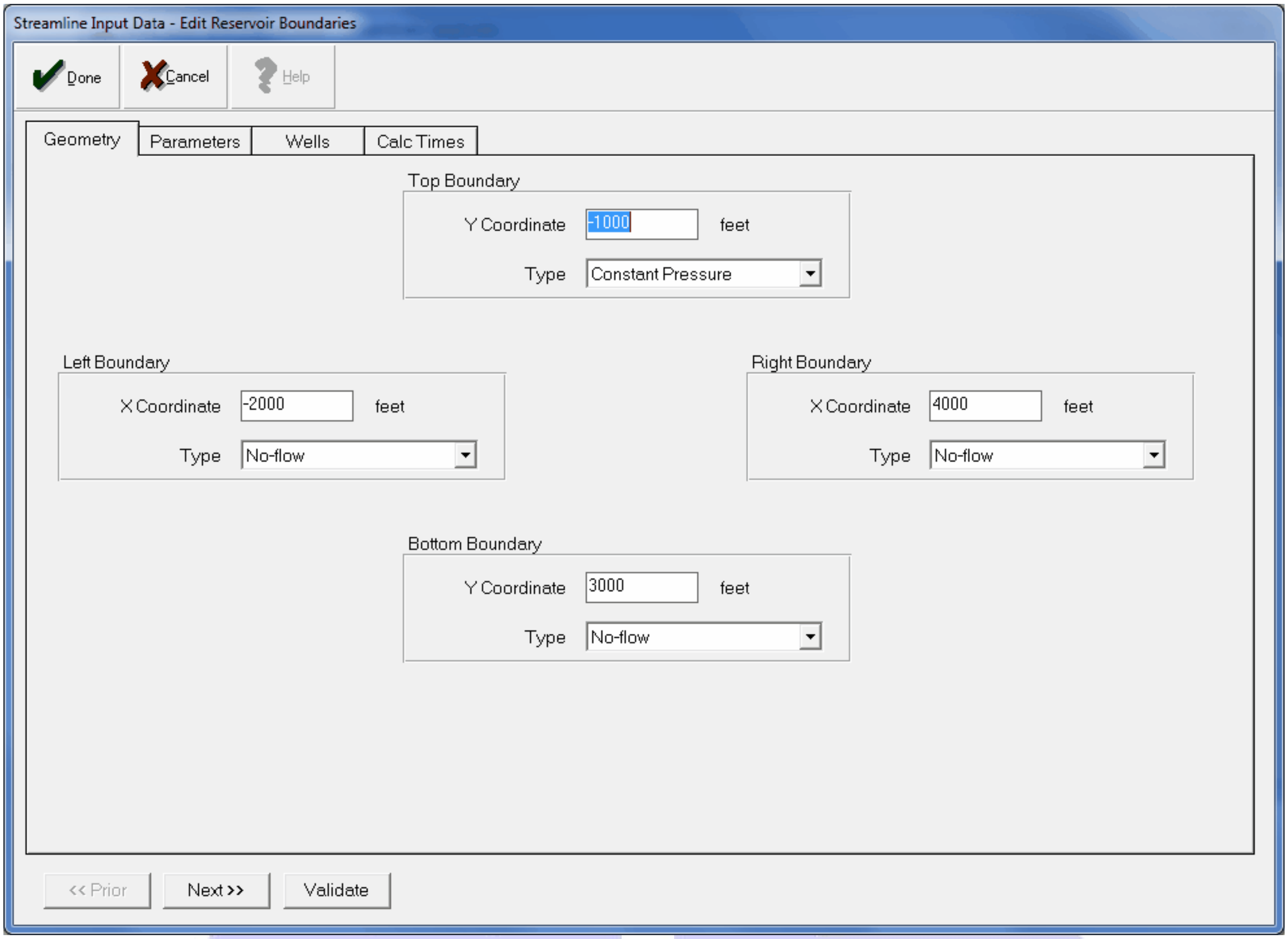
PVT input data is similar to material balance input. More information is available in this section

Describing the PVT 70 and PVT for Oil 75.

2.11.3.1 Geometry

GEOMETRY

With respect to reservoir geometry, the input data for the streamline model requires a description of the co-ordinates of the rectangular reservoir model as shown below. The co-ordinates of all the four boundaries can be defined and the boundary type can be set as constant pressure or no-flow. Constant pressure boundaries will account for aquifer effects for example:


Streamline Input Data - Edit Reservoir Boundaries
Done
Cancel
Help
Geometry
Parameters
Wells
Calc Times
<< Prior
Next >>
Validate

Top Boundary

Y Coordinate -1000 feet

Type Constant Pressure

Left Boundary

X Coordinate -2000 feet

Type No-flow

Right Boundary

X Coordinate 4000 feet

Type No-flow

Bottom Boundary

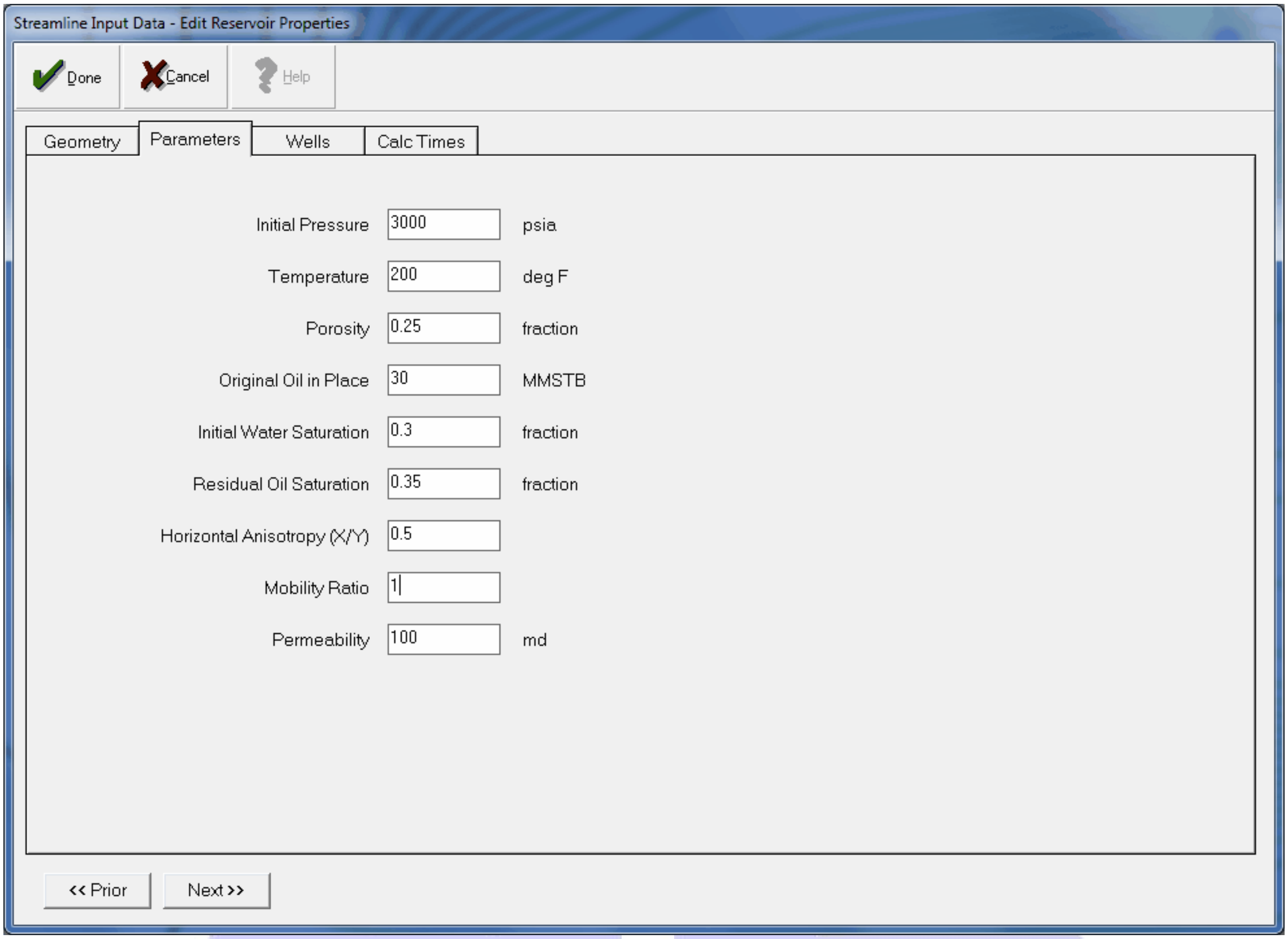
Y Coordinate 3000 feet

Type No-flow

2.11.3.2Tank Parameters

PARAMETERS

Average reservoir parameters are defined within this section:

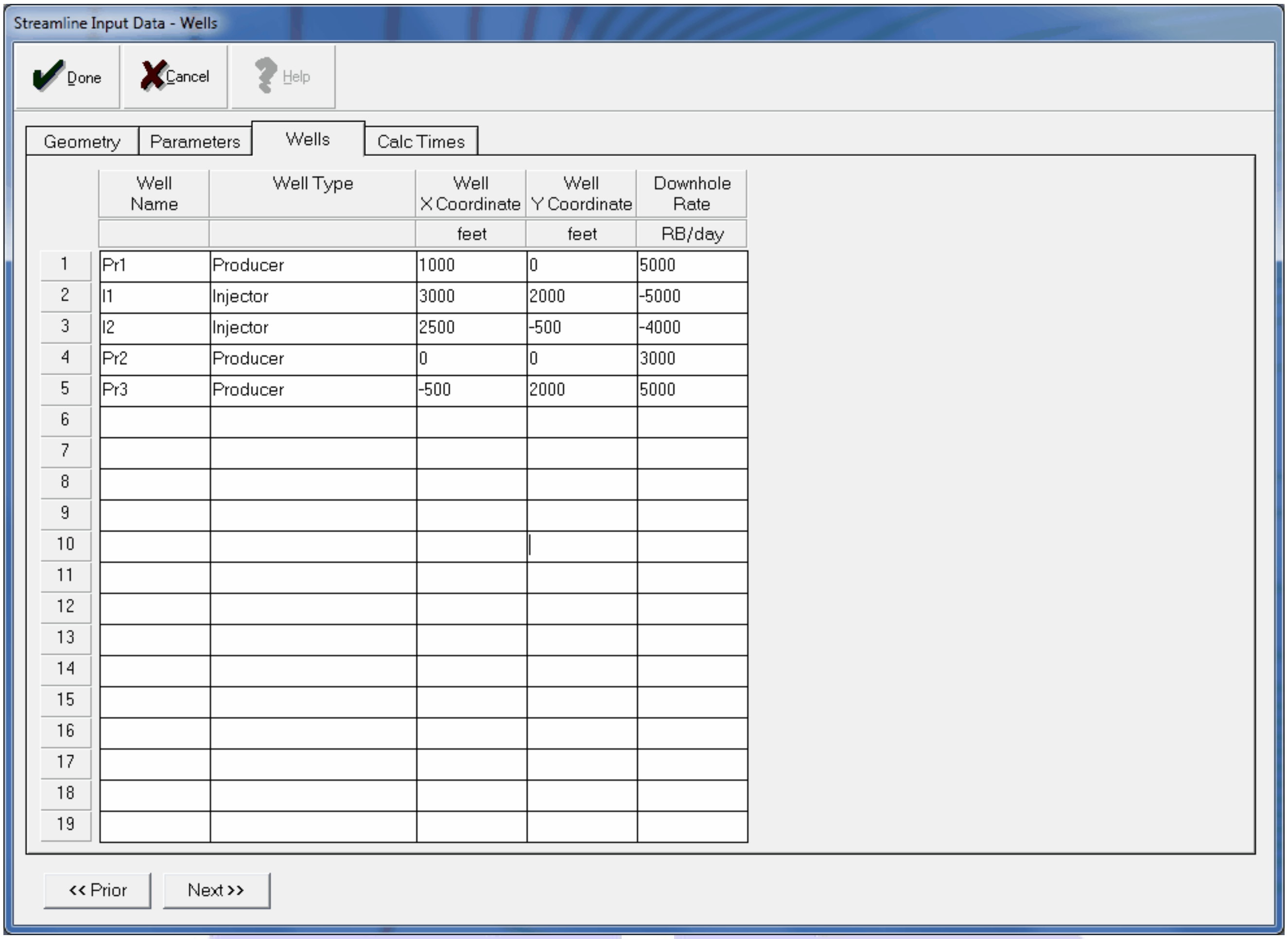

Streamline Input Data - Edit Reservoir Properties
Done
Cancel
Help
Geometry
Parameters
Wells
Calc Times
<< Prior
Next >>

Initial Pressure	3000	psia
Temperature	200	deg F
Porosity	0.25	fraction
Original Oil in Place	30	MMSTB
Initial Water Saturation	0.3	fraction
Residual Oil Saturation	0.35	fraction
Horizontal Anisotropy (X/Y)	0.5	
Mobility Ratio	1	
Permeability	100	md

2.11.3.3Wells

WELLS

This sections allows defining the position of the wells (using co-ordinates) within the reservoir model. The downhole rates are also defined with producers modelled with positive rates specfied and injectors defined by the input negative rates. With the positions and flow across the wells properly defined, the streamlines can be evaluated.

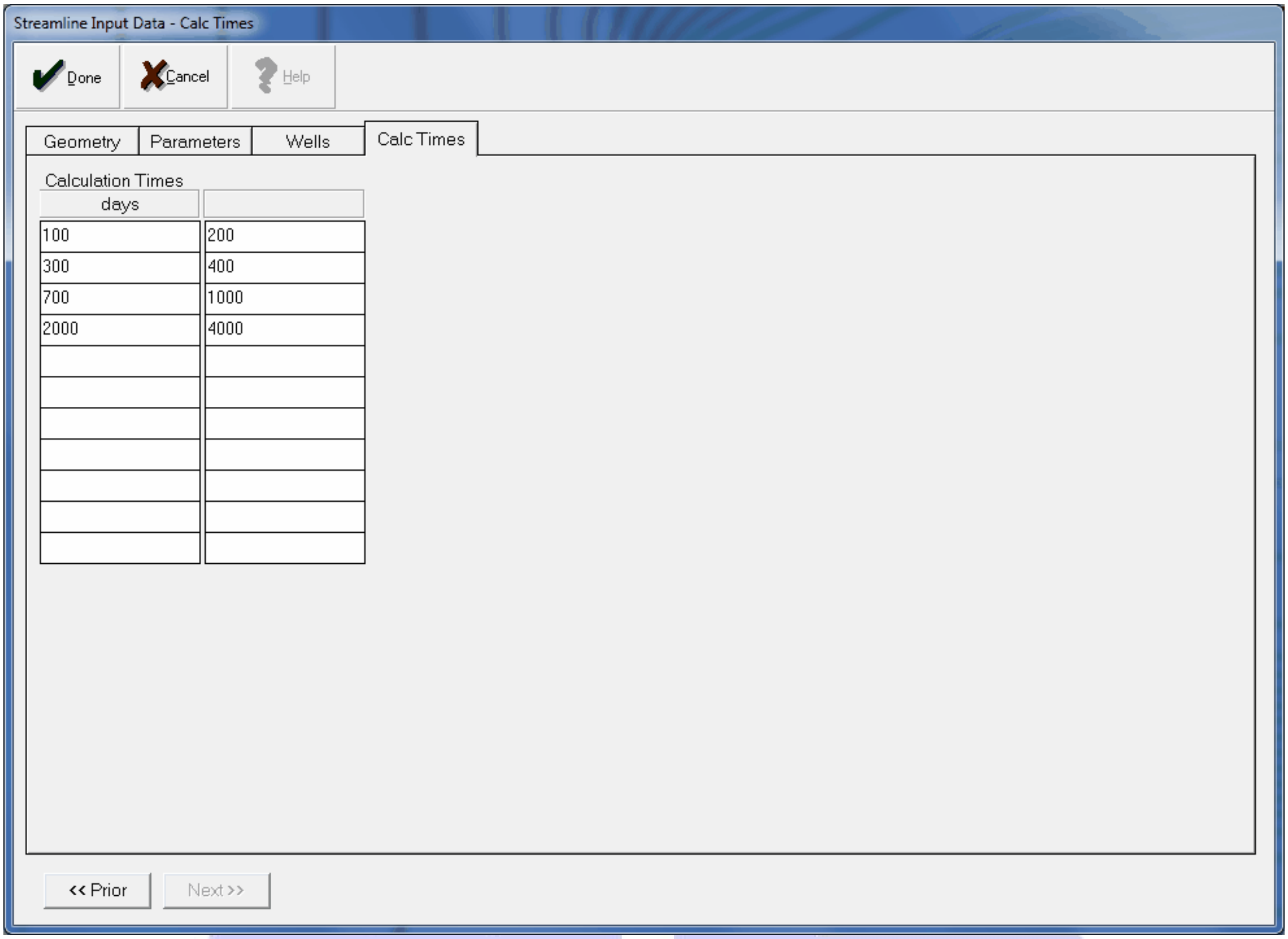

Streamline Input Data - Wells
Done
Cancel
Help
Geometry
Parameters
Wells
Calc Times
<< Prior
Next >>

	Well Name	Well Type	Well X Coordinate	Well Y Coordinate	Downhole Rate
			feet	feet	RB/day
1	Pr1	Producer	1000	0	5000
2	I1	Injector	3000	2000	-5000
3	I2	Injector	2500	-500	-4000
4	Pr2	Producer	0	0	3000
5	Pr3	Producer	-500	2000	5000
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					

2.11.3.4Calculation times

CALCULATION TIMES

The required timesteps for the calculations are specified on this interface:


Streamline Input Data - Calc Times
Done
Cancel
Help
Geometry
Parameters
Wells
Calc Times
<< Prior
Next >>

Calculation Times

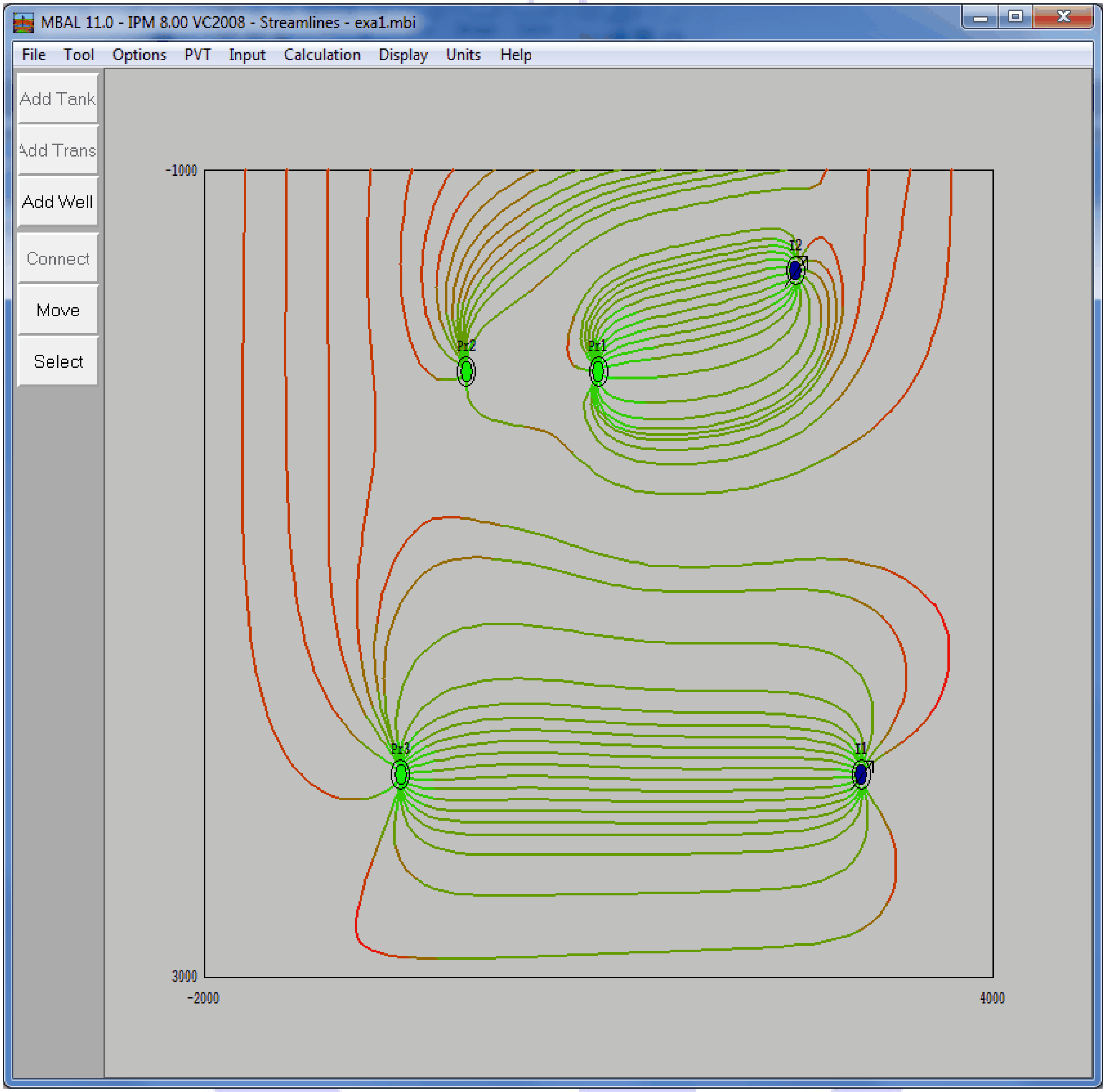
days	
100	200
300	400
700	1000
2000	4000

2.11.4 Results

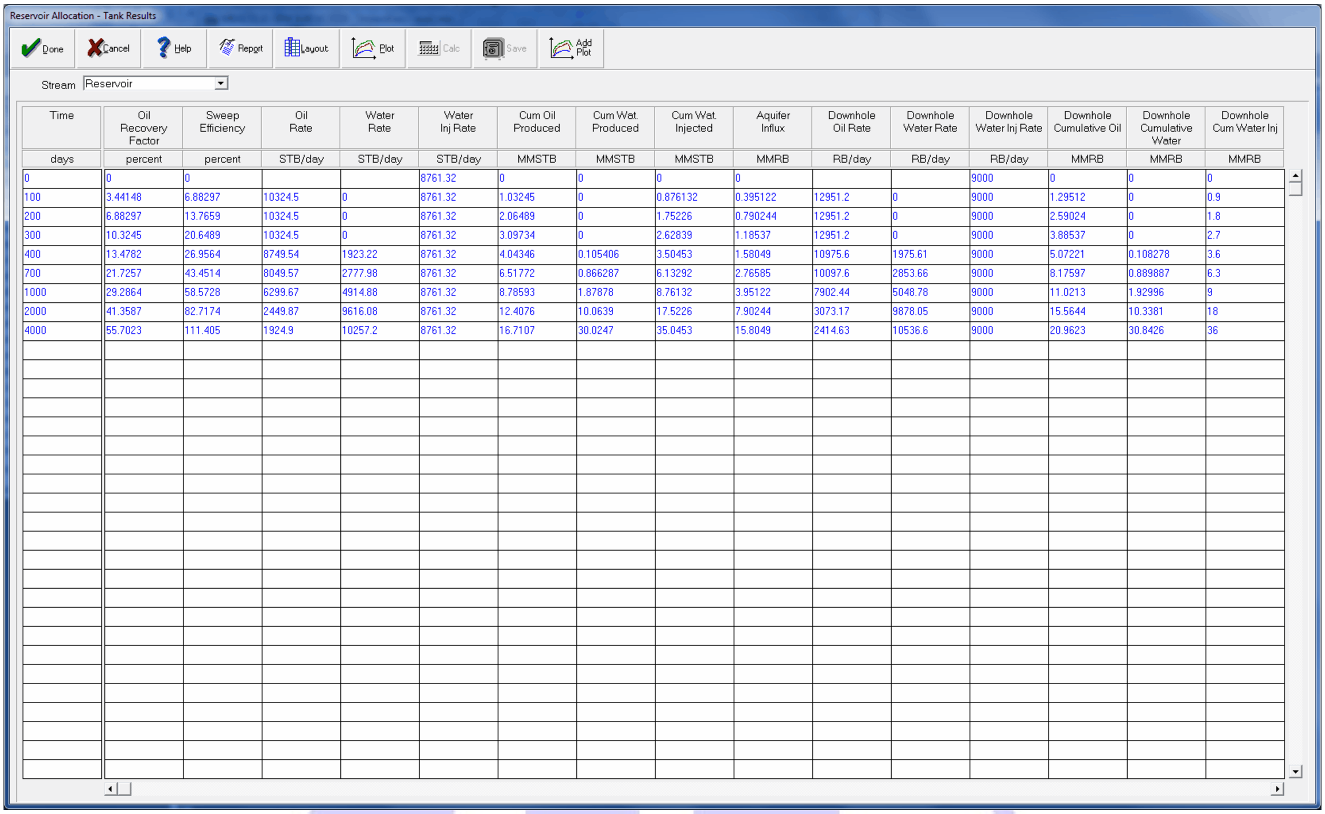
The streamlines calculation provides the following outputs:

- Breakthrough times
- The Fw curve for each producing well is calculated. This can be used to generate rel perm sets for the wells in the material balance tool.
- Tracks which injector is supporting which producer and by how much (%).
- The streamlines can be used to calculate the sweep efficiency of well configuration.

Once the calculation is performed, the streamlines calculated can be visually inspected within the main interface.


MBAL 11.0 - IPM 8.00 VC2008 - Streamlines - exa1.mbi
File
Tool
Options
PVT
Input
Calculation
Display
Units
Help
Add Tank
Add Trans
Add Well
Connect
Move
Select
-1000
3000
-2000
4000
I2
Pr2
Pr1
Pr3
I1

The results can also be obtained by selecting Calculation | Calculation results



Stream: Reservoir

Time	Oil Recovery Factor	Sweep Efficiency	Oil Rate	Water Rate	Water Inj Rate	Cum Oil Produced	Cum Wat. Produced	Cum Wat. Injected	Aquifer Influx	Downhole Oil Rate	Downhole Water Rate	Downhole Water Inj Rate	Downhole Cumulative Oil	Downhole Cumulative Water	Downhole Cum Water Inj
days	percent	percent	STB/day	STB/day	STB/day	MMSTB	MMSTB	MMSTB	MMRB	RB/day	RB/day	RB/day	MMRB	MMRB	MMRB
0	0	0			8761.32	0	0	0	0			9000	0	0	0
100	3.44148	6.88297	10324.5	0	8761.32	1.03245	0	0.876132	0.395122	12951.2	0	9000	1.29512	0	0.9
200	6.88297	13.7659	10324.5	0	8761.32	2.06489	0	1.75226	0.790244	12951.2	0	9000	2.59024	0	1.8
300	10.3245	20.6489	10324.5	0	8761.32	3.09734	0	2.62839	1.18537	12951.2	0	9000	3.88537	0	2.7
400	13.4782	26.9564	8749.54	1923.22	8761.32	4.04346	0.105406	3.50453	1.58049	10975.6	1975.61	9000	5.07221	0.108278	3.6
700	21.7257	43.4514	8049.57	2777.98	8761.32	6.51772	0.866287	6.13292	2.76585	10097.6	2853.66	9000	8.17597	0.889887	6.3
1000	29.2864	58.5728	6299.67	4914.88	8761.32	8.78593	1.87878	8.76132	3.95122	7902.44	5048.78	9000	11.0213	1.92996	9
2000	41.3587	82.7174	2449.87	9616.08	8761.32	12.4076	10.0639	17.5226	7.90244	3073.17	9878.05	9000	15.5644	10.3381	18
4000	55.7023	111.405	1924.9	10257.2	8761.32	16.7107	30.0247	35.0453	15.8049	2414.63	10536.6	9000	20.9623	30.8426	36

2.12 Appendix

2.12.1 A - References

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2.12.2 B - MBAL Equations

2.12.2.1 Material Balance Equations

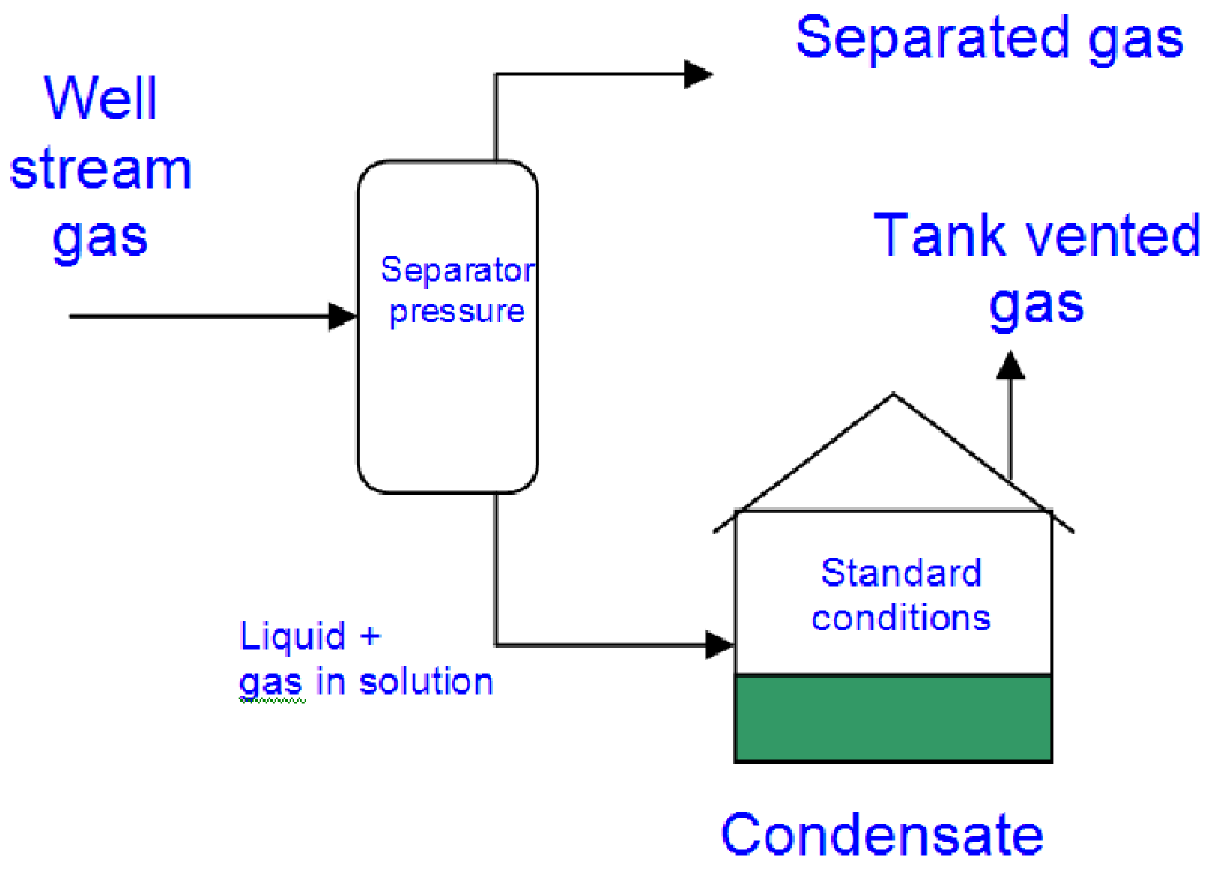
The following pages show some of the equations used in the MBAL program. Please refer to a basic reservoir engineering text for a detailed treatment of graphical history matching techniques. The nomenclature for the following equations is given towards the end of Appendix B 484.

2.12.2.1.1 PVT

2.12.2.1.1.1 Gas Equivalent

The dry-wet gas model in **MBAL** assumes that the condensate drops out at the separator assuming single phase (gas) in the tubing. (Besides any possible water produced which will give two-phase flow).

The objective is to obtain the properties of the well stream gas from the separated gas, tank vented gas and condensate. (Please see next diagram).


Well stream gas
Separator pressure
Separated gas
Tank vented gas
Standard conditions
Liquid + gas in solution
Condensate

The ideal way to do this is to perform a compositional analysis where the composition of the gas separated, condensate and the gas vented are known. Then these fluids are recombined to get the well stream composition and properties.

However most of time the compositions are unknown, and also the quantity and gas specific gravity of the stock tank gas vented are often not measured.

In those cases, correlations can be used to calculate the gas specific gravity and the GE (Gas equivalent) or VEQ (volume equivalent).

The VEQ or GE represents the volume of gas vented in the tank plus the volume in scf that would be occupied by a barrel of stock-tank liquid if it were gas.

MBAL is using a correlation that depends on the separator pressure to calculate the GE.

The GE is added to the gas rate and used to calculate the pressure losses in the tubing using the energy balance equation.

In fact from the diagram above we can see the separator pressure dependency, for instance if the separator pressure is 0 psig, the tank vented gas will be zero, if the separator pressure is higher then more gas will pass in solution with the liquid towards the tank. So the separator pressure has an impact on GE.

Other correlations of GE available in the literature that depends on the separator pressure can be found in the following references: “An Improved method for the determination of the Reservoir gas specific gravity for retrograde gases” Gold et.al., also the in the book “The properties of Petroleum Fluids” W. McCain (Chapter 7: Properties of Wet Gases) explains and show some these correlations available.

2.12.2.1.2 OIL

The general material balance equation for an oil reservoir is expressed as

$$F = N\ E_t + W_e$$

Where the underground withdrawal *F* equals the surface production of oil, water and gas corrected to reservoir conditions:

$$F = N_p * \left(B_o - B_g * R_s\right) + B_g * \left(G_p - G_i\right) + \left(W_p - W_i\right) * B_w$$

and the original oil in place is *N* stock tank barrels and *E* is the per unit expansion of oil (and its dissolved gas), connate water, pore volume compaction and the gas cap.

$$E_t = \left(B_o - B_{oi}\right) + \left(R_{si} - R_s\right)B_g + m\,B_{oi}\left(\frac{B_g}{B_{gi}} - 1\right) + \left(1 + m\right)B_{oi}\left[\frac{S_{wc}\,c_w + c_f}{1 - S_{wc}}\right]\left(P_i - P\right)$$

Graphical interpretation methods are based on manipulating the basic material balance expression to obtain a straight line plot when the assumptions of the plotting method are valid. For example, when there is no aquifer influx, $W_e = 0$, and:

$$F = N\ E_t$$

$$\frac{F}{E_t} = N$$

A plot of F/E_t should be a horizontal straight line with a Y axis intercept equal to the oil-in-place *N*. This plot is a good diagnostic for identification of the reservoir drive mechanism. If the aquifer model is correct, the following manipulation shows that a plot

$$F - W_e = N\ E_t$$

of *F-We* against E_t will yield a straight line with a slope of *N*. The procedure is to adjust the aquifer model until the best straight line fit is obtained. A more sensitive plot is obtained by dividing through by E_t as follows:

$$\frac{F}{E_t} = N + \frac{W_e}{E_t}$$

When the aquifer model is accurate, the plot of F/E_t vs. W_e/E_t will yield a straight line with unit slope and a y-axis intercept at N.

2.12.2.1.3 GAS

The general material balance equation for a gas reservoir is expressed as

$$F = GE_t + W_e$$

Where:

$$F = B_g\ (G_p - G_i) + B_w(W_p - W_i)$$

and

$$E_t = \left(B_g - B_{gi}\right) + B_{gi}\left[\frac{S_{wc}c_w + c_f}{1 - S_{wc}}\right](P_i - P)$$

2.12.2.1.4 Graphical History Matching Methods: Oil

2.12.2.1.4.1 Havlena - Odeh

Basic material balance equation for oil is

$$F = N\ E_t + W_e$$

Rearranging the equation we get,

$$\frac{F}{E_t} = N + \frac{W_e}{E_t}$$

Now we plot F/Et vs sum(dP*Q(td))/Et. The RHS is actually calculated using We/U where U is the multiplier normally used to convert sum(dP*Q(td)) to We. However this only works if the method of calculating water influx is indeed modelled by U*sum(dP*Q(td)).

2.12.2.1.4.2 F/Et versus We/Et

The general material balance equation can be written as:

$$F = N\,E_t + W_e$$

Dividing both sides by Et

$$\frac{F}{E_t} = N + \frac{W_e}{E_t}$$

Now, if F/Et versus We/Et is plotted, then the Y intercept will be equal to N and the slope of the line must be equal to 1.

2.12.2.1.4.3 (F - We)/Et versus F (Campbell)

Basic material balance equation for oil is

$$F = N\,E_t + W_e$$

Rearranging the equation we get,

$$\frac{F - W_e}{E_t} = N$$

Now, if (F - We) / Et versus F is plotted, a horizontal line with Y intercept equal to N should be obtained.

If the history points deviate from the horizontal, it indicates the model is not able to predict the response as seen from the reservoir. The input data must be reviewed in this case.

2.12.2.1.4.4 (F - We) versus Et

Basic material balance equation for oil is

$$F = N\,E_t + W_e$$

Rearranging the equation we get,

$$F - W_e = N\ E_t$$

Plotting (F - We) versus Et should give N as the slope and a Y intercept of 0.

2.12.2.1.4.5 (F - We) / (Eo + Efw) versus Eg / (Eo + Efw)

The basic material balance equation with Et written in the expanded form

$$F = N\left(E_o + m\ E_g + E_{fw}\right) + W_e$$

Rewriting this equation as

$$F - W_e = N\left(E_o + E_{fw}\right) + N\ m\ E_g$$

Dividing both sides by (Eo + Efw)

$$\frac{F - W_e}{\left(E_o + E_{fw}\right)} = N + \frac{mNE_g}{\left(E_o + E_{fw}\right)}$$

Now if we plot (F - We)/ (Eo + Efw) versus Eg / (Eo + Efw), the Y intercept is equal to N and the slope equal to mN. If there is no primary gas cap then the plot should be a horizontal straight line.

2.12.2.1.4.6 F / Et versus F (Campbell - No Aquifer)

Basic material balance equation for oil is

$$F = N\ E_t + W_e$$

If there is no aquifer influx then We = 0.

Rearranging the equation we get,

$$\frac{F}{E_t} = N$$

Now, if F / Et versus F is plotted, a horizontal line with Y intercept equal to N should be obtained.

2.12.2.1.5 Graphical History Matching Methods: Gas

2.12.2.1.5.1 P/Z

The general material balance equation for gas given above can be converted to a more popular form of

$$\frac{P}{Z} = \frac{P_i}{Z_i}\left[1 - \frac{G_p}{G}\right]$$

The underlying assumptions to arrive at this equation is that there is no aquifer influx and the connate and rock compressibilities are negligible. Only depletion drive due to gas expansion is considered.

Thus if we plot P/Z versus the gas production G_p, the plot is a straight line; y-intercept equal to P_i /Z_i and the Gas in Place (G) can be obtained from the slope of the line.

2.12.2.1.5.2 P/Z (Overpressured)

The P/Z equation for abnormally pressured reservoirs is the same as the P/Z equation mentioned above, except that the connate water and rock compressibilities are not considered negligible. The general material balance equation for this method is expressed as

$$F = G\left(E_g + E_{fw}\right)$$

where E_{fw} is the term expressing connate water expansion and pore volume reduction.

There are two methods to express the above equation in a graphical manner.

Re-arrange the above equation we obtain:

$$\frac{P}{Z}\left[1 - c_e\left(P_i - P\right)\right] = \frac{P_i}{Z_i}\left[1 - \frac{G_p}{G}\right]$$

where $c_e = \dfrac{c_f + c_w S_w}{1 - S_{wc}}$

If $\frac{P}{Z}\left(1-c_e\left(P_i-P\right)\right)$ is plotted against G_p the Y intercept represents P_i/Z_i and the Gas in Place (G) can be obtained from the slope.
On the plot, the X Axis is represented as $(G_p - G_i)$ where G_i is the quantity of gas injected.

2.12.2.1.5.3 Havlena Odeh (Overpressured)

Basic material balance equation for gas is:

$$F = G\,E_g + G\,E_{fw} + W_e$$

Taking W_e over to the LHS and then dividing through by E_g gives:

$$\frac{F - W_e}{E_g} = G + G\frac{E_{fw}}{E_g}$$

Plotting $(F-W_e)/E_g$ vs E_{fw}/E_g gives a slope and a Y intercept of G.

2.12.2.1.5.4 Havlena & Odeh (water drive)

This method is similar to the Havlena & Odeh - Overpressured method discussed above. For this method the factors E_g and E_{fw} are combined to form E_t.

$$F = GE_t + W_e$$

Dividing through by E_t gives:

$$\frac{F}{E_t} = G + \frac{W_e}{E_t}$$

If F/E_t is plotted against W_e/E_t then a line with unit slope and a Y intercept at G. Note this works only in the presence of an aquifer.

2.12.2.1.5.5 Cole ((F-We)/Et)

$$F = GE_t + W_e$$

So taking everything over to the LHS except for the G, we get:

$$\frac{F - W_e}{E_t} = G$$

So we plot the LHS vs gas production and we should get a straight horizontal line intersecting the Y axis at G. This can also be valid when the LHS is plotted against time on the X - Axis.

2.12.2.1.5.6 Roach (unknown Compressibility)

For this method, the original p/z equation is corrected Ce (using pz to represent p/z and pzi to represent pi/zi):

$$pz\left(1 - c_e\left(P_i - P\right)\right) = p_i z_i - \frac{p_i z_i}{G} G_p$$

$$p_i z_i = \frac{p_i z_i}{G} G_p + pz\left(1 - c_e\left(P_i - P\right)\right)$$

$$p_i z_i = \frac{p_i z_i}{G} G_p + pz - pzc_e\left(P_i - P\right)$$

$$p_i z_i - pz = \frac{p_i z_i}{G} G_p - pzc_e\left(P_i - P\right)$$

$$\frac{p_i z_i}{pz} - 1 = \frac{p_i z_i}{pzG} G_p - c_e\left(P_i - P\right)$$

$$\frac{\frac{p_i z_i}{pz} - 1}{\left(P_i - P\right)} = \frac{G_p p_i z_i}{pzG\left(P_i - P\right)} - c_e$$

Therefore if we plot,

$$\frac{\frac{p_i z_i}{pz} - 1}{\left(P_i - P\right)} \quad vs \quad \frac{G_p p_i z_i}{pz\left(P_i - P\right)}$$

a slope equal to 1/G is obtained and the Y intercept is $-c_e$.

2.12.2.1.5.7 Cole - No Aquifer (F/Et)

This method is the same as the Cole method described above, except that the aquifer influx is assumed zero.

$$\frac{F}{E_t} = G$$

If the tank has no aquifer then this method will be the same as Cole ((F-We/Et) method.

2.12.2.1.6 Reservoir Voidage

The 'Reservoir Voidage' for a particular timestep can be calculated from the total quantity of fluids extracted from the tank and the PVT properties of the fluids.

The reservoir voidage at a certain timestep *i* is given by:

$$\begin{aligned} RV_i = & \left[\left(Np_i - Np_{i-1} \right) * Bo_i * 5.615 \right] \\ & + \left\{ \left[(Gp_i - Gp_{i-1}) - \left(Np_i - Np_{i-1} \right) * Rs_i \right] * Bg_i \right\} \\ & + \left[\left(Wp_i - Wp_{i-1} \right) * Bw_i * 5.615 \right] \end{aligned}$$

Where:

RV = reservoir voidage in cf

Np = Cumulative Oil Production at that timestep in stb

Bo = Oil Formation Volume Factor in rb/stb

Gp = Cumulative Gas Production at that timestep in scf

Rs = Solution GOR in scf/stb

Bg = Gas Formation Volume Factor in cf/scf

Wp = Cumulative Water Production in stb

Bw = Water Formation Volume Factor in rb/stb

i = indicates the timestep

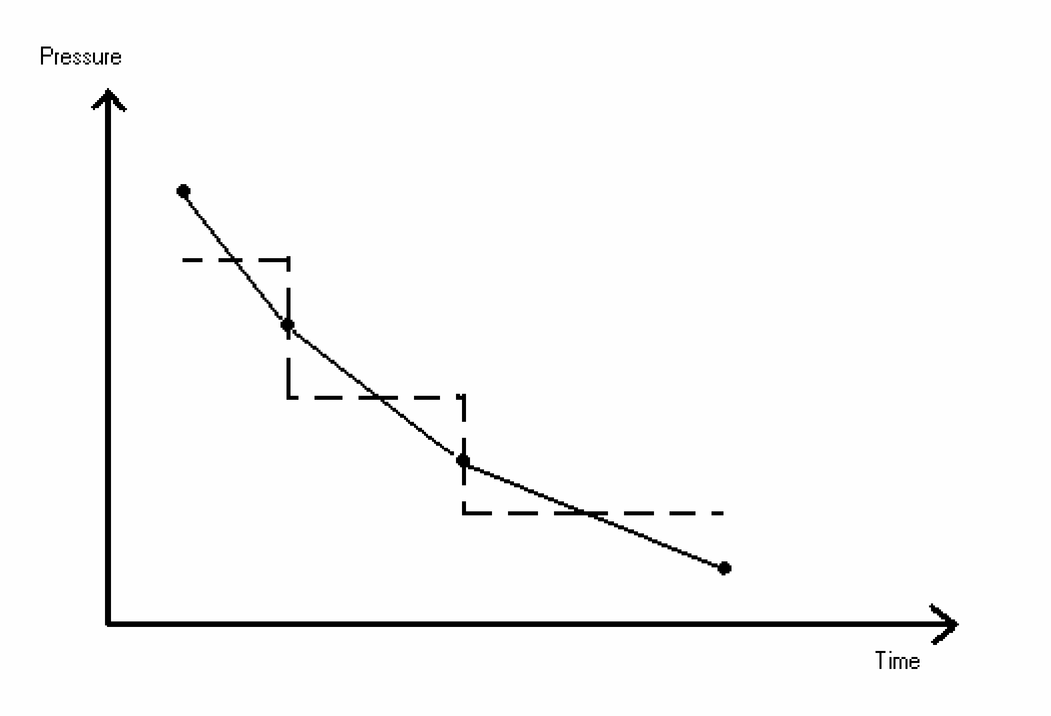
2.12.2.2 Aquifer Models

In the following sections, the various aquifer models available in **MBAL** are described along with the references.

The equations shown below describe the methods of calculating the aquifer influx for the various models. The models include:

- Small Pot
- Schilthuis Steady State
- Hurst Steady State
- Hurst-van Everdingen-Odeh
- Hurst-van Everdingen-Dake
- Vogt-Wang
- Fetkovitch Semi Steady State
- Fetkovitch Steady State
- Hurst-van Everdingen Modified
- Carter-Tracy

Small Pot	This model assumes that the aquifer is of a fixed volume V_a and the water influx from the aquifer to the reservoir is time independent. The influx from the aquifer is related to the pressure drop through the total average compressibility of the system (water + rock). The equation describing the influx is thus given by: $W_e(t) = 5.615\,(C_w + C_f)V_a(P_i - P_n)$ where Va = aquifer volume Pi = Initial pressure P_n = Pressure at time t. C_w = Water compressibilty C_f = Rock compressibility See Dake L.P.: “Fundamentals of reservoir engineering”, Chapter 9 for more details.
Schilthuis Steady State	This model assumes that the flow is time dependent but is a steady state process. It approximates the water influx function by, $\frac{dW_e}{dt} = A_c(P_i - P)$ (Eq 1.2a) where, A_c is the productivity constant of the aquifer in RB/psi/day. Assuming it is constant over time, this equation on integration gives,

	$W_e(t) = A_c \int_0^t (P_i - P)dt$ (Eq 1.2b) The numerical approximation for this integral is done using the following formula with W_e expressed is MMRB, $W_e(t) = 10^{-6} A_c \sum_{j=1}^{n} \left[P_i - \frac{(P_j + P_{j-1})}{2} \right] (t_j - t_{j-1})$ (Eq1.2c) The pressure decline is approximated as shown in the following diagram  **Reservoir Pressure decline approximation with time** See Tehrani D.H.: "Simultaneous Solution of Oil-In-Place and Water Influx parameters for Partial Water Drive reservoirs with Initial Gas Cap", SPE 2969 for more details.
Hurst Steady State	It is another simplified model. The influx is defined by the following equation $\frac{dW_e}{dt} = \frac{A_c (P_i - P)}{\log(\alpha \times t)}$ (Eq1.3a) The influx is found by integrating,

	$W_e = \int_0^t \frac{A_c(P_i - P)}{\log(\alpha \times t)} dt$ (Eq1.3b) The numerical approximation to this integral is with the influx in MMRB, $W_e(t) = 10^{-6} A_c \sum_{j=1}^{n} \left[P_i - \frac{(P_j + P_{j-1})}{2} \right] \frac{(t_j - t_{j-1})}{\ln(\alpha \times (t_j - t_0))}$ (Eq1.3c) Where A_C is the aquifer constant entered in the aquifer model input and has units RB/psi/day. Alpha is the time constant. See Tehrani D.H.: “Simultaneous Solution of Oil-In-Place and Water Influx parameters for Partial Water Drive reservoirs with Initial Gas Cap”, SPE 2969 for more details.
Hurst-van Everdingen-Dake	The Hurst-van Everdingen-Dake model is essentially the same as the Hurst-van Everdingen-Odeh model. The only difference is instead of entering the tD constant and aquifer constant directly, we enter the various physical parameters (e.g. permeability, reservoir radius) that are used to calculate the two constants. Once we have calculated these constants, they are used in the summation formula in exactly the same way as the Hurst-van Everdingen-Odeh model. There is one other slight variation with the Odeh model. For all Hurst-van Everdingen-Dake models, for each term in the summation MBAL uses the fluid properties at the pressure for the time in the summation term. So in the summation formula above, the U and alpha are calculated using the fluid properties with the pressure at tj. This is an improvement to the original published model where the fluid properties were taken from the pressure at tn. Note that this correction is obviously not possible in the Odeh model as the tD and alpha constants are entered as single values for all time steps. All the models previously discussed with the exception of Hurst simplified are based on the assumption that the pressure disturbance travels instantaneously throughout the aquifer and reservoir system. On the other hand if we do not make this assumption, then it indicates that the speed will depend on the pressure diffusivity of the system. Radial System The pressure diffusivity equation representing the behaviour for a radial system can be written as, $\frac{1}{r_D} \frac{\partial}{\partial r_D} \left(r_D \frac{\partial P_D}{\partial t_D} \right) = \frac{\partial P_D}{\partial t_D}$ (Eq1.4a)

where

$$r_D = \frac{r}{r_o}$$

r_o being the outer radius of the reservoir

$$t_D = \alpha * t = \frac{kt}{\varphi\mu(C_w + C_f)r_o^2}$$

(Eq1.4b)

α is pressure diffusivity of the system and is also called t_D constant in **MBAL**.

ϕ = Porosity

μ = Viscosity of water

C_w = water compressibility

C_f = Formation compressibility

k = Permeability of the aquifer.

In modelling aquifer behaviour since we are interested in finding rates with pressure changes, this diffusivity equation solved for constant terminal pressure i.e. constant pressure at reservoir-aquifer boundary gives the following general solution,

$$W_e = U \times \Delta P \times W_D(t_D, R_D)$$

(Eq1.4c)

where

R_D = reservoir radius/ aquifer outer radius

U is called aquifer constant and in field units it is given by,

$$U = \frac{1.119\ A_e \phi h (C_f + C_w) r_o^2}{360.0}$$

A_e = Encroachment angle in degrees

h = Reservoir thickness in feet

Similarly the t_D constant in oil field units (day^{-1}) is given by,

$$\alpha = \frac{2.309\ k_a}{365.25\ \phi \mu_w (C_f + C_w) r_o^2}$$

The function WD is called dimensionless aquifer function and is depends on dimensionless time and the size of the aquifer with respect to the reservoir. There are algebraic approximations to the WD function available[3] this form is the most general form of the equation as it gives the behaviour of the pressure diffusivity equation for both the finite and infinite acting aquifers (bounded) depending on the value of R_D.

In real production, this terminal pressure (at the reservoir-aquifer boundary) does not remain constant, but changes. Hurst-Van-Everdingen and Dake using the principle of superposition solved this problem. They found the real-time water influx using Eq1.4c and approximating the pressure decline as a step function shown as dashed lines in figure1. The water influx equation thus after superposition is given by,

$$W_e(t) = 10^{-6}\sum_{j=o}^{n-1} U\Delta P_j W_D\left(\alpha\left(t_n - t_j\right), R_D\right) \qquad \text{(Eq1.4d)}$$

And,

$$\Delta P_j = \left(P_{j-1} - P_{j+1}\right)/2$$

If j=0 i.e. the first, use P_i i.e. initial reservoir pressure, instead of P_{j-1}

Linear Aquifers

The pressure diffusivity equation as represented for the radial can also be set up for linear aquifers and a constant terminal pressure solution found. The form of the solution is exactly similar to the radial one, except for the definition of t_D constant and U. These are defined as,

$$W_e(t) = 10^{-6}\sum_{j=o}^{n-1} U\Delta P_j W_D\left(\alpha\left(t_n - t_j\right)\right) \qquad \text{(Eq1.4e)}$$

$$\alpha = \frac{2.309\,k}{365.25\,\phi\mu_w\left(C_f + C_w\right)L_a^2}$$

$$U = 10^6 V_a\left(C_f + C_w\right)/5.615$$

Where:

$$L_a = \frac{10^6 V_a}{\left(W_r \phi h\right)}$$

V_a = Aquifer volume

W_r = Reservoir width

L_a= length of the aquifer

Bottom Drive

The bottom drive aquifer models are the same as the linear models. The only difference from linear models is the surface through which the influx is taking place. For bottom drive aquifers the surface available from influx is □r_w^2. The length used for finding the t_D constant is the dimension perpendicular to this surface. These are calculated in oil field units as follows

$$\alpha = \frac{2.309\,k_a}{365.25\,\phi \mu_w \left(C_f + C_w\right) L_a^2}$$

$$U = 10^6 V_a \left(C_f + C_w\right) / 5.615$$

Where

$$L_a = \frac{10^6 V_a}{\left(\pi r_o^2 \phi\right)}$$

In equation Eq1.4e the form of the influx function depends on the boundary conditions considered at the outer aquifer boundary. The boundary conditions available within **MBAL** are

Infinite acting

This form assumes that the aquifer length is infinite; the value of aquifer length is infinite. However for finding t_D constant the value of L_a can be an arbitrary constant. In **MBAL** we choose a very large value for Va and then estimate La.

Sealed boundary

This form takes the aquifer to be finite with a length La and finds the aquifer function as of this value.

Constant pressure boundary

This form assumes that during the whole time the outer boundary of the aquifer is at a constant pressure.

Note In all the original models the constant U is treated as constant all through the time. However in **MBAL**, while doing summations during superposition, U value components like compressibility and PVT properties are evaluated at

	the current reservoir pressure. See Dake L.P.: “Fundamentals of reservoir engineering”, Chapter 9 and Nabor et al.: “Linear Aquifer behaviour”, JPT May 1964, SPE 791 for more details.
Hurst-van Everdingen-Odeh	The Hurst-van Everdingen-Odeh model is essentially the same as the Hurst-van Everdingen-Dake model. The only difference is instead of entering all the aquifer dimensions to evaluate aquifer constant and t_D constant we enter the values of the constants as directly. The dimensionless solutions i.e. W_D functions are the same as of the Hurst-van Everdingen Dake method. The assumption in this model is that the rate and pressure stay constant over the duration of each time step. $$W_e(t) = 10^{-6}\sum_{j=o}^{n-1} U\Delta P_j W_D\left(\alpha\left(t_n - t_j\right), R_d\right)$$ where: Rd = Outer/Inner radius ratio from the inputs - only used for radial aquifers $\Delta P_j = \left(P_{j-1} - P_{j+1}\right)/2$ if j=0, use P_0 instead of P_{j-1} Alpha = tD constant from the inputs U = Aquifer constant from the inputs
Vogt-Wang	This model is exactly the same as the Hurst-van Everdingen-Dake modified model. It also assumes a linear pressure decline in each time step. To find the influx in each time step, it uses the convolution theorem to give the following expression for influx, $$W_e = U \times \frac{\Delta P}{t_D}\int_0^{t_D} W_D\left(t_D - \tau\right)d\tau$$ (Eq1.7a) Since, the function is linear, it uses superposition and the water influx is approximated as, $$W_e\left(t_{Dn}\right) = U\left[\frac{P_i - P_1}{t_{D1}}\int_0^{t_{D1}} W_D\left(t_{Dn} - \tau\right)d\tau + \frac{P_1 - P_2}{t_{D2} - t_{D1}}\int_{t_{D1}}^{t_{D2}} W_D\left(t_{Dn} - \tau\right)d\tau + \ldots\ldots + \frac{P_{n-1} - P_n}{t_{Dn} - t_{Dn-1}}\int_{t_{Dn-1}}^{t_{Dn}} W_D\left(t_{Dn} - \tau\right)d\tau\right]$$ (Eq1.7b) For each time step the convolution integral for each time step can be broken

	into two integrals by change of variable from as follows, $\int_{t_{Di}}^{t_{Di+1}} W_D(t_{Dn}-\tau)d\tau = \int_0^{t_{Dn}-t_{Di}} W_D(u)du - \int_0^{t_{Dn}-t_{Di+1}} W_D(u)du$ (Eq1.7c) This substitution into the water influx function gives the following result with influx as MMRB $W_e(t_n) = 10^{-6}U\sum_{j=0}^{n-1}\Delta P_j \int_0^{t_{Dj}} W_D(t_D)\times t_D$ (Eq1.7d) Where if j = 0, $\Delta P_0 = \frac{P_1 - P_0}{\alpha(t_1 - t_0)}$ Otherwise, $\Delta P_j = \frac{P_{j+1} - P_j}{\alpha(t_{j+1} - t_j)} - \frac{P_j - P_{j-1}}{\alpha(t_j - t_{j-1})}$ See Vogt J.P. and Wang B.: “Accurate Formulas for Calculating the Water Influx Superposition Integral.”, SPE 17066 for more details.
Fetkovitch Semi Steady State	In the semi-steady state model, the pressure within the aquifer is not kept constant but allowed to change. Material balance equation is used to find that the changed average pressure in the aquifer. Based on this fact the influx is worked out to be, $W_e = \frac{W_{ei}}{P_i}(P_i - P)\left[1 - \exp\left(-\frac{JP_i}{W_{ei}}\right)\right]$ (Eq1.9a) Where Wei is the maximum encroachable water influx, J is the aquifer productivity index. Pi is the initial pressure and P is the reservoir pressure. For different flow geometry the values of these two constants are: Radial Model $W_{ei} = 3.14159\ (C_f + C_w)A_e r_w^2(R_d^2 - 1)h\phi P_i/360.0 * 5.615$ $J = \frac{0.00708\ A_e k_a h}{360.0\mu_w(\log(R_d) - 0.75)}$ Linear Model $W_{ei} = 10^6(C_w + C_f)V_a P_0/5.615$

$$J = \frac{0.00381\ k_a h W_r}{\mu_w L_a}$$

$$L_a = \frac{10^6 V_a}{W_r h \phi}$$

Bottom Drive

$$W_{ei} = 10^6 \left(C_w + C_f\right) V_a P_0 / 5.615$$

$$J = \frac{0.00381\ k_a \pi r_w^2}{\mu_w L_a}$$

$$L_a = \frac{10^6 V_a}{\pi r_w^2 \phi}$$

This influx equation Eq1.9a is still valid only for a constant reservoir pressure P. In case the reservoir pressure also is declining; the influx is calculated using the principle of superposition. For the first time step, the influx is,

$$W_1 = \frac{W_{ei}}{P_i}\left(P_i - \overline{P_1}\right)\left(1 - \exp\left(-\frac{JP_i}{W_{ei}}\Delta t_1\right)\right)$$

(Eq1.9b)

For the nth time step the influx is,

$$W_n = \frac{W_{ei}}{P_i}\left(\overline{P_{an}} - \overline{P_n}\right)\left(1 - \exp\left(-\frac{JP_i}{W_{ei}}\Delta t_n\right)\right)$$

(Eq1.9c)

Where $\overline{P_{an}}$ and $\overline{P_n}$ are the average aquifer and reservoir pressure in the time step.

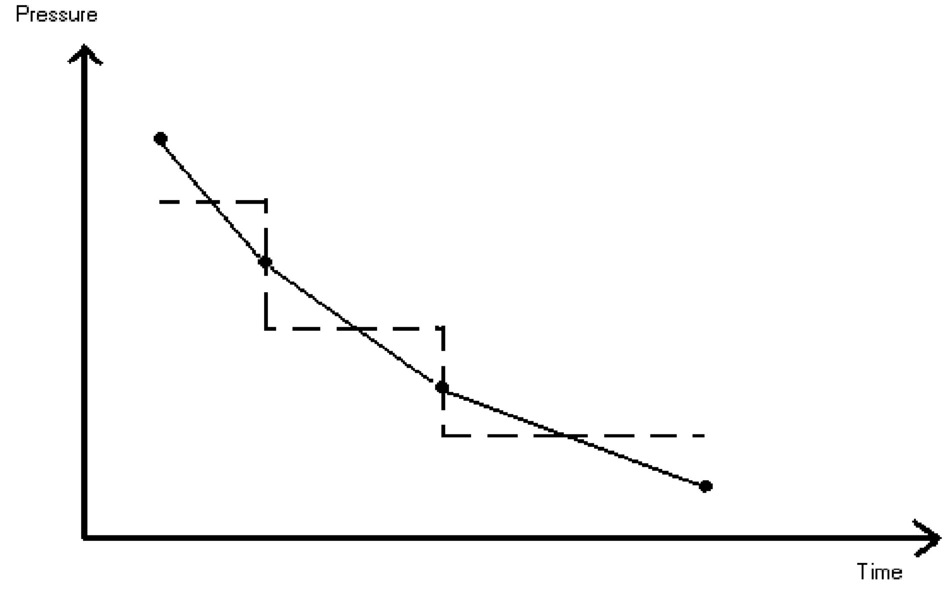
These are calculated as follows,

$$\overline{P_n} = \frac{P_{n-1} - P_n}{2}$$ and $P_0=P_I$

$$\overline{P_{an}} = P_i\left(1 - \frac{\sum_{j=1}^{n-1} W_j}{W_{ei}}\right)$$

Based on these the superposition formula gives the following result for aquifer influx in MMRB,

	$W_e = 10^{-6}\sum_{j=0}^{n-1}\frac{W_{ei}}{P_i}\left(\overline{P_{aj}} - \frac{P_j + P_{j+1}}{2}\right)\left(1.0 - e^{-X}\right)$ (Eq1.9d) Where $X = JP_i\left(t_{j+1} - t_j\right)/W_{ei}$, $P_1 = P_i\left(1 - \frac{W_{last}}{W_{ei}}\right)$ W_{last} being the aquifer influx up to j-1 time step. See Fetkovich M.J.: “A Simplified Approach to Water Influx calculations --- Finite Aquifer System”, SPE 2603 for more details.
Fetkovitch Steady State	The Fetkovich theory looks at water influx as well inflow calculated using productivity index. Thus, the influx rate is a function given as, $\frac{dW_e}{dt} = J(P_i - P)$ (Eq1.8a) In the steady state model, the productivity index is calculated similar to a Darcy well inflow model. This PI is supposed to remain constant. Depending on the geometry the PI is calculated as follows in oil field units: Radial $J = \frac{0.00708\ A_s k_a h}{360.0 \mu_w \log_2 (R_d)}$ Linear $J = \frac{0.00127\ k_a h W_r}{\mu_w L_a}$ Bottom Drive $J = \frac{0.00127\ k_a \pi r_w^2}{\mu_w L_a}$ See Fetkovich M.J.: “A Simplified Approach to Water Influx calculations --- Finite Aquifer System”, SPE 2603 for more details.
Hurst-van Everdingen Modified	This method is similar to the Hurst-van Everdingen Dake model. The main difference is the manner in which the pressure decline is approximated. In the original model the decline is approximated as a series of time steps with constant pressure. In the modified one it is approximated as a linear decline for each time step. As shown in the solid lines of the figure below:



The broken line shows the method of integration used for the standard Hurst-van Everdingen-Dake model. The solid line shows the linear interpolation used in the Hurst-van Everdingen-Modified model.

This approach allows us to have varying rate within a time step rather than it being constant as in the original method. The solution for this case is the integral of the dimensionless solution of the constant terminal pressure case.

$$W_e = U\int_{P_i}^{P} W_D(t_D)dP \qquad \text{(Eq1.6a)}$$

This solution changed into time domain becomes,

$$W_e = \int_0^{t_D} W_D(t_D)\frac{dP}{dt_D}dt_D \qquad \text{(Eq1.6b)}$$

Since pressure decline with time is linear, dP/dt_D is a constant equal to slope of the linear pressure decline, given by,

$$\frac{dP}{dt_D} = \frac{1}{\alpha}\frac{P_i - P}{t}$$

The influx function thus becomes for the linear decline,

$$W_e = U\times\frac{(P_i - P)}{\alpha\times t}\int_0^{t_D} W_D(t_D)dt_D \qquad \text{(Eq1.6c)}$$

Since the functions are linear, we can use superposition again. Thus, if we approximate the pressure decline by a series of linear declines, the water influx solution is given by,

$$W_e(t_n) = 10^{-6}\sum_{j=o}^{n-1}\frac{U}{\alpha}\frac{\Delta P_j}{t_j - t_{j+1}}\int_{t_D}^{t_{D_n}} W_D(t_D)dt_D$$

(Eq1.6d)

Where the form of WD, tD constant and U depend on the model being linear, bottom drive or radial and are same as the ones used in original Hurst-van Everdingen model.

The general form:

$$W_e(t_n) = 10^{-6}\sum_{j=o}^{n-1} U \frac{\Delta P_j}{t_i - t_{i+1}}\int W_D dt$$

where:

Rd = Outer/Inner radius ratio from the inputs - only used for radial aquifers

$$\Delta P_j = (P_j - P_{j+1})$$

Alpha and U depend on the model.

For radial models:

$$\alpha = \frac{2.309\, k_a}{365.25\phi\mu_w(C_f + C_w)r_w^2}$$

$$U = \frac{1.119\, A_e\phi h(C_f + C_w)r_w^2}{360.0}$$

where:

ka = Aquifer permeability
rw = Reservoir radius
Ae = Encroachment angle
h = Reservoir thickness

For linear models:

$$\alpha = \frac{2.309\, k_a}{365.25\phi\mu_w(C_f + C_w)L_a^2}$$

$$U = 10^6 V_a(C_f + C_w)/5.615$$

where:

$$L_a = \frac{10^6 V_a}{(W_r\phi h)}$$

Va = Aquifer volume
Ka = Aquifer permeability
Wr = Reservoir width
h = Reservoir thickness

For bottom drive:

	$\alpha = \frac{2.309\,k_a}{365.25\phi\mu_w\left(C_f + C_w\right)L_a^2}$ $U = 10^6 V_a\left(C_f + C_w\right)/5.615$ where: $L_a = \frac{10^6 V_a}{\left(\pi r_w^2 \phi\right)}$ Va = Aquifer volume Ka = Aquifer permeability rw = Reservoir radius h = Reservoir thickness For all Hurst-van Everdingen-Modified models, for each term in the summation **MBAL** uses the fluid properties at the pressure for the time in the summation term. So in the summation formula above, the U and alpha are calculated using the fluid properties with the pressure at tj. This is an improvement to the original model where the fluid properties were taken from the pressure at tn.
Carter-Tracy	The principal difference between this method and the Hurst-van Everdingen models is as follows. The Hurst-van Everdingen models assume a constant pressure over a time interval and thus use the constant terminal pressure solution of the diffusivity equation with the principle of superposition to find the water influx function. Carter Tracy model on the other hand uses the constant terminal rate solution and expresses the aquifer influx as a series of constant terminal rate solutions. The dimensionless function thus is the pressure written ad P_D function. The water influx equation thus by Carter Tracy method is, $W_e\left(t_n\right) = 10^{-6} U \sum_{j=o}^{n-1} \frac{\Delta P_j - W_e\left(t_{n-1}\right) P_D^{'}\left(t_{Di}\right)}{P_D\left(t_{Di}\right) - t_{Di} P_D^{'}\left(t_{Di}\right)} \left(t_{Di+1} - t_{Di}\right)$ (Eq1.10) Where the various constants are defined as, $\Delta P_j = \left(P_0 - P_{j+1}\right)$ $t_{Di} = \alpha\left(t_i - t_0\right)$ $\alpha = \frac{2.309\,k_a}{365.25\,\phi\mu_w\left(C_f + C_w\right)r_w^2}$ $U = \frac{1.119\,A_e\phi h\left(C_f + C_w\right)r_w^2}{360.0}$ The form of the equation is such that we do not need superposition to

	calculate the water influx, but only the water influx up to previous time step. As such because of the constant rate solution being the generator, it is basically a steady-state model. Also, it is used only for radial geometry. For each term in the summation **MBAL** uses the fluid properties at the pressure for the time in the summation term. So in the summation formula above, alpha is calculated using the fluid properties with the pressure at time tj. This is an improvement to the original model where the fluid properties were taken from the pressure at tn. See Carter R.D. and Tracey G.W.: “An Improved Method for Calculating Water Influx”, JPT Sep. 1960, SPE 2072 for more details.

2.12.2.3Relative Permeability

The equations shown below cover the Corey functions and Stones modifications to the relative permeability functions.

2.12.2.3.1 Corey Relative Permeability Function

In a Corey function, the relative permeability for the phase x is expressed as:

$$Krx = Ex * \left(\frac{Sx - Srx}{Smx - Srx} \right)^{nx}$$

where:

Ex is the end point for the phase x,
nx the Corey Exponent,
Sx the phase saturation,
Srx the phase residual saturation and
Smx the phase maximum saturation.

The phase absolute permeability can then be expressed as:

Kx = K * Krx where: - K is the reservoir absolute permeability and
- Krx the relative permeability of phase x.

2.12.2.3.2 Stone method 1 modification to the Relative Permeability Function

Krw and Krg are calculated as for normal function.

Kro is calculated using both oil relative permeability curves; oil relative to water only and oil relative to gas with only connate water.

First calculate Som (combined residual oil saturation):

Som = a.Sorw + (1 – a).Sorg

where

a = 1.0 – Sg/(1.0 – Swc – Sorg)

Next correct the saturations:

So = (So – Som)/(1.0 – Swc – Som)
Sw = (Sw – Swc)/(1.0 – Swc – Som)
Sg = Sg/(1.0 – Swc – Som)

Finally:

$$k_{ro} = \frac{S_o}{(1-S_w)(1-S_g)}\left[\frac{k_{row}\,k_{rog}}{k_{ro}(S_{wc})}\right]$$

2.12.2.3.3 Stone method 2 modification to the Relative Permeability Function

$$Kro = Krocw * \left(\left(\frac{Krow}{Krocw} + Krw\right) * \left(\frac{Krog}{Krocw} + Krg\right) - Krw - Krg\right)$$

Krog = oil relative permeability in the presence of oil, gas and connate water,

Krow = oil relative permeability in the presence of oil and water only.

Krocw = oil relative permeability in the presence of connate water only,

2.12.2.4Nomenclature

Awe	Fraction Of Reservoir Area Invaded By Water Influx
Bg	Gas Formation Volume Factor
Bo	Single-Phase Oil Formation Factor
Bt	Two-Phase Oil Formation Factor
Bw	Water Formation Volume Factor
cf	Formation Compressibility
cw	Water Compressibility
Efw	Expansion Of Water And Reduction In Pore Volume
Eg	Expansion Of Gas
Eo	Expansion Of Oil And Solution Gas
Er	Recovery Efficiency
Et	Overall Expansion Of Oil, Gas And Water & Formation

Ev	Volumetric Sweep Efficiency
F	Underground Withdrawal
Ft	Total Trapped Gas Volume In Hcpv
G	Original Gas In Place
Gi	Cumulative Gas Injection
GLp	Cumulative Condensate Produced
Gp	Cumulative Gas Production
Gt	Trapped Wet Gas
Gwgp	Cumulative Wet Gas Produced
h	Net Thickness
HCPV	Hydrocarbon Pore Volume
Kc	Condensate Conservation Factor
Ktd	Dimensionless Time Coefficient
Ktd	Theoretical Dimensionless Time Coefficient
k	Absolute Permeability
Krg	Gas Relative Permeability
Kro	Oil Relative Permeability To Gas
Kw	Effective Permeability To Water In The Aquifer
Kwrg	Effective Permeability To Water At Residual Gas Saturation
L1	Distance Of Linear Gas Reservoir At Current Gas Water Contact
L2	Distance Of Linear Gas Reservoir At Original Gas Water Contact
MLc	Molecular Weight Of Condensate
m	Initial Gascap Size, Defined As The Ratio Of Initial Gascap Hcpv To Initial Oil Zone Hcpv
N	Original Oil In Place
Np	Cumulative Oil Production
OGWC	Original Gas Water Contact
P	Average Reservoir Pressure

P1	Average Pressure In Front Of Current Gas Water Contact
P2	Pressure At Original Gas Water Contact
Pb	Bubble-Point Pressure
Pt	Average Pressure In Water Invaded Region
Pwf	Flowing Bottomhole Pressure
qo	Oil Production Rate
qw	Water Influx Rate
Qd	Dimensionless Water Influx
r1	Radius Of Gas Reservoir At Current Gas Water Contact
r2	Rg
ra	Aquifer Radius
re	External Radius
rg	Radius Of Gas Reservoir At Original Gas Water Contact
ro	Radius Of Oil Reservoir At Original Oil Water Contact
rw	Wellbore Radius
Rp	Cumulative Gas-Oil Ratio
Rs	Instantaneous Producing Gas-Oil Ratio
S	Well Skin Factor
Sgc	Critical Gas Saturation
Sgr	Residual Gas Saturation
Sor	Residual Oil Saturation To Water
Swi	Initial Water Saturation
S(P,t)	Aquifer Function
T	Reservoir Temperature
t	Time
tD	Dimensionless Time
TDF	Dimensionless Time Adjusting Factor
U	Aquifer Constant

U	Theoretical Aquifer Constant
Vaq	Pore Volume Of Aquifer
W	Width Of Linear Reservoir
We	Cumulative Water Influx
Wi	Cumulative Water Injection
Z	Gas Deviation Factor
Φ	Porosity
Θ	Dip Angle
μ	Viscosity
ψ	Influx Encroachment Angle
γ**c**	Specific Gravity Of Condensate
γ**w**	Specific Gravity Of Formation Water
σ	Normalized Standard Deviation

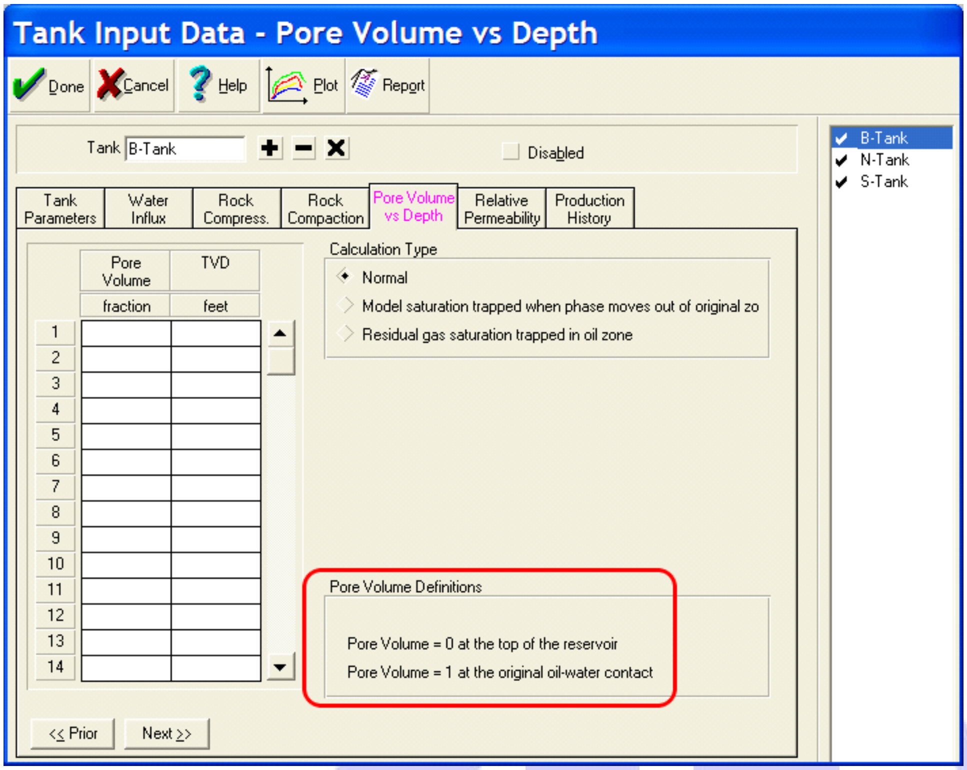
2.12.2.4.1 Subscripts

a	minimum abandonment pressure condition
a_w	watered-out abandonment condition
g	gas
i	initial condition
j	index of loops
o	oil
1	location at current gas water contact
2	location at original gas water contact
sc	standard condition
t	trapped gas in water invaded region
w	water

2.12.3 C - Fluid Contacts Calculation details

2.12.3.1 D-1 Pore Volume vs. Depth

This screen is used to define the 'Pore Volume vs. Depth'. To access this screen, choose Input| Tank Data and select the Pore Volume vs. Depth tab. A dialogue box as seen below will be displayed:


Tank Input Data - Pore Volume vs Depth
Done
Cancel
Help
Plot
Report
Tank B-Tank
Disabled
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
Pore Volume fraction
TVD feet
1
2
3
4
5
6
7
8
9
10
11
12
13
14
<< Prior
Next >>
B-Tank
N-Tank
S-Tank

Calculation Type
● Normal
○ Model saturation trapped when phase moves out of original zo
○ Residual gas saturation trapped in oil zone

Pore Volume Definitions

Pore Volume = 0 at the top of the reservoir

Pore Volume = 1 at the original oil-water contact

Material Balance analysis for reservoirs is based on treating the system as a dimensionless tank. The traditional approach does not allow consideration of fluid contact depths and their movements, (GOC or OWC or GWC) as no geology is provided.

In **MBAL** the addition of Pore Volume vs. Depth table introduces a means of allowing contact movements. Pore volume is directly related to saturations of phases in the reservoir and these in turn are related to a given depth through this table.

Let us assume a situation where an aquifer is providing support to an oil reservoir. The aquifer will provide water that will encroach in the tank, thus increasing the water saturation. In classical material balance calculations, the water saturation in the tank will increase as a single number (no variation of Sw in the reservoir). However, if the increase in water saturation is related to a pore volume fraction, then the increase in the OWC can be calculated based on the PV vs. Depth table.

This tab is enabled only if the *Monitor Contacts* option in the Tank Parameters data sheet has been activated. The table displayed is used to calculate the depth of the different fluid contacts. ***This table must be entered for variable PVT tanks***.

The definitions for entering 'Pore Volume' fractions are displayed in the 'Definitions' section in this page as shown above. The definitions will automatically change depending on the fluids present in the tank at initial conditions. Some details are provided below:

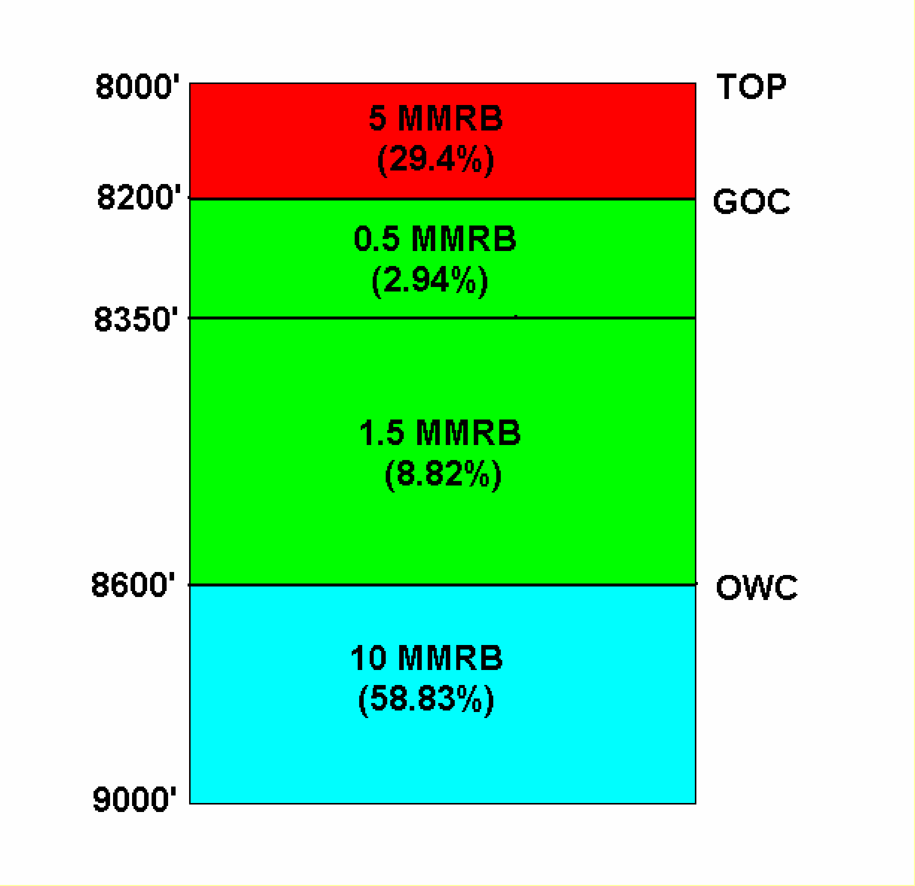
P **or**	**Below GOC:** Pore Volume Fraction = (pore volume from top of oil leg to the depth of interest)/ (total

e Volume vs. Depth for Oil Reservoirs

oil leg pore volume)

Above GOC:
Pore Volume Fraction = - (pore volume from top of oil leg to depth of interest)/ (total gas cap volume)

For example, for the case below:


8000'
TOP
5 MMRB
(29.4%)
8200'
GOC
0.5 MMRB
(2.94%)
8350'
1.5 MMRB
(8.82%)
8600'
OWC
10 MMRB
(58.83%)
9000'

Total gas cap pore volume = 5 MMRB
Total oil leg pore volume = 2 MMRB
Oil pore volume fraction at 8200' = 0.0
Oil pore volume fraction at 8350' from GOC = 0.5 / 2 = 0.25
Oil pore volume fraction at 8600' from GOC = 2 / 2 = 1.0
Gas pore volume fraction at 8000' = - 5 / 5 = -1.0

So enter PV vs. Depth table:

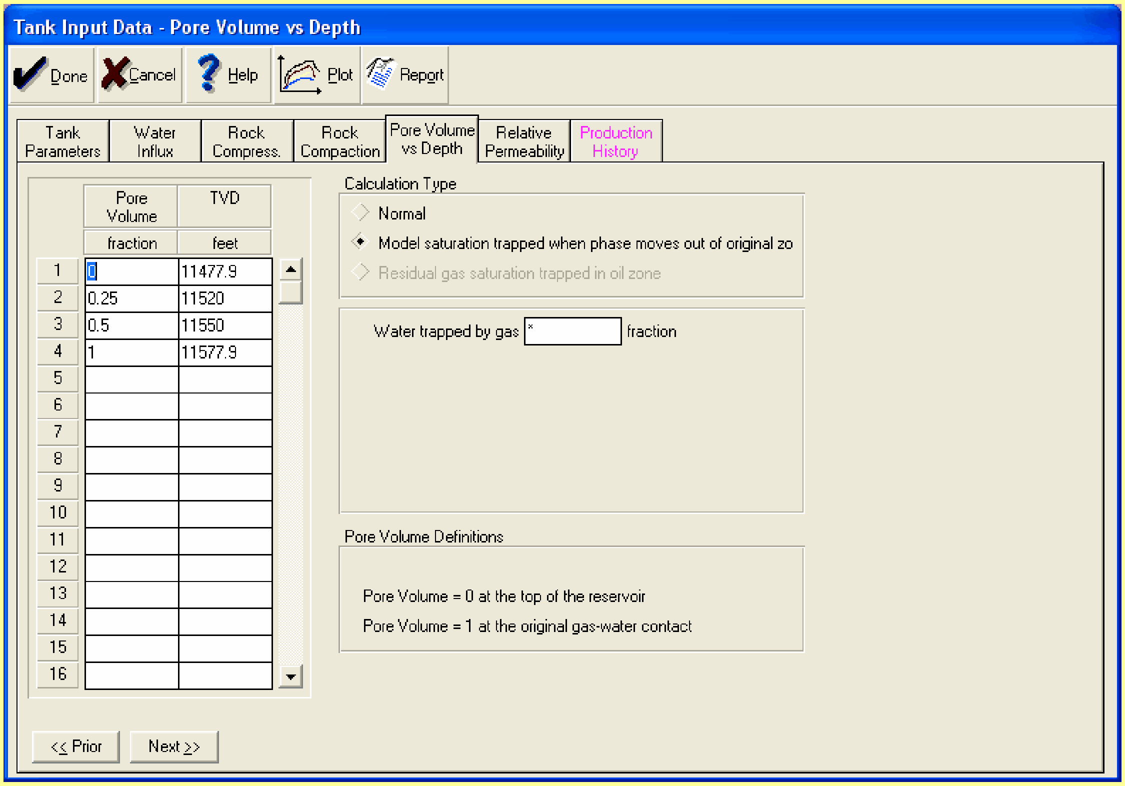
PV	TVD
-1.0	8000
0.0	8200

0.25	8350
1.0	8600

Pore Volume vs Depth for Dry & Wet Gas Models.

The data here would be identical to that for an oil reservoir.

In the case of a Dry and Wet Gas Model only two options would be available for the user as shown below:


Tank Input Data - Pore Volume vs Depth
Done
Cancel
Help
Plot
Report
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
<< Prior
Next >>

	Pore Volume fraction	TVD feet
1	0	11477.9
2	0.25	11520
3	0.5	11550
4	1	11577.9
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		

Calculation Type
○ Normal
● Model saturation trapped when phase moves out of original zo
○ Residual gas saturation trapped in oil zone

Water trapped by gas * fraction

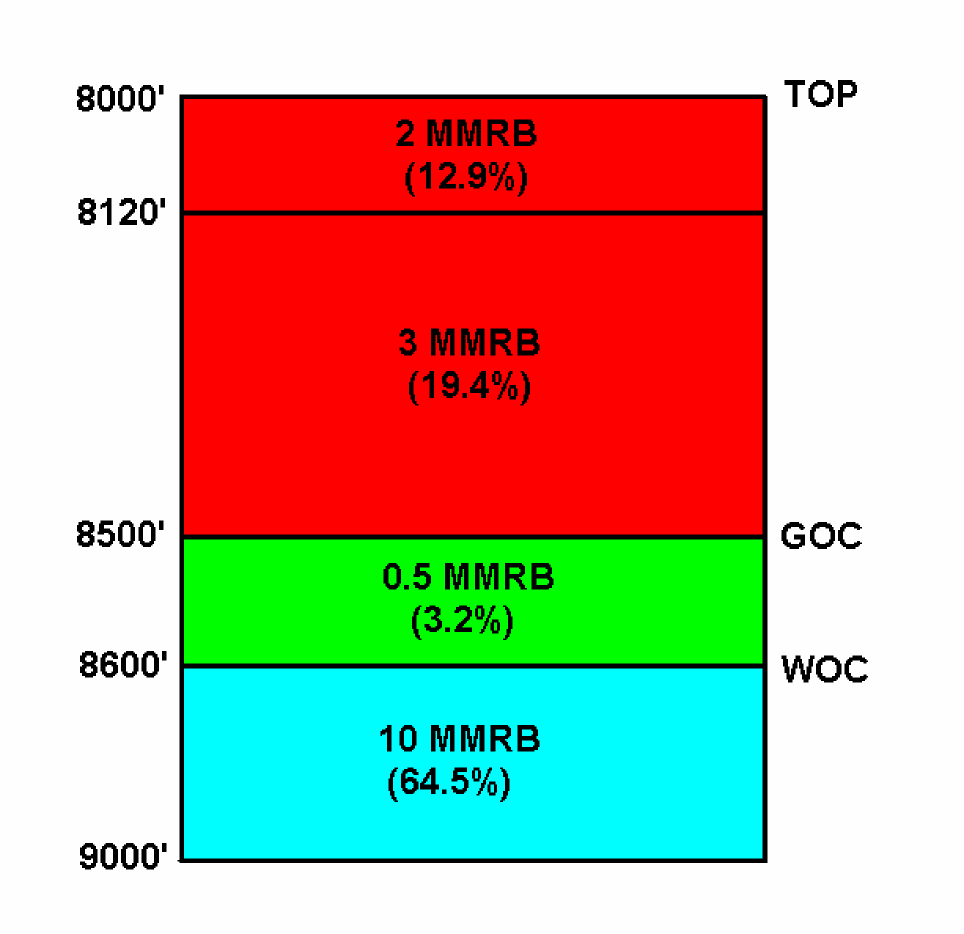
Pore Volume Definitions
Pore Volume = 0 at the top of the reservoir
Pore Volume = 1 at the original gas-water contact

NORMAL: the pore volume vs. depth table to calculate the corresponding depth

Model Saturation Trapped when Phase Moves out of Original Zone:

This option for the water trapped by GAS is applicable when the fluid contacts start to encroach back into the original phase. For example:

1) If we consider a GWC originally at 5000 ft
2) Then over time water encroaches into the reservoir so that GWC rises to 4950 ft
3) During this time, the water trapped by gas is not considered. It is assumed that the saturation trapped behind is the {residual saturation of the phase + the sweep efficiency if defined)
4) If the GWC starts to fall again from 4950 ft to 4980 ft, then this is where the water trapped by gas saturation will be used.
5) In this case, the saturation of water trapped between 4950 ft and 4980 ft is the value specified in the column.

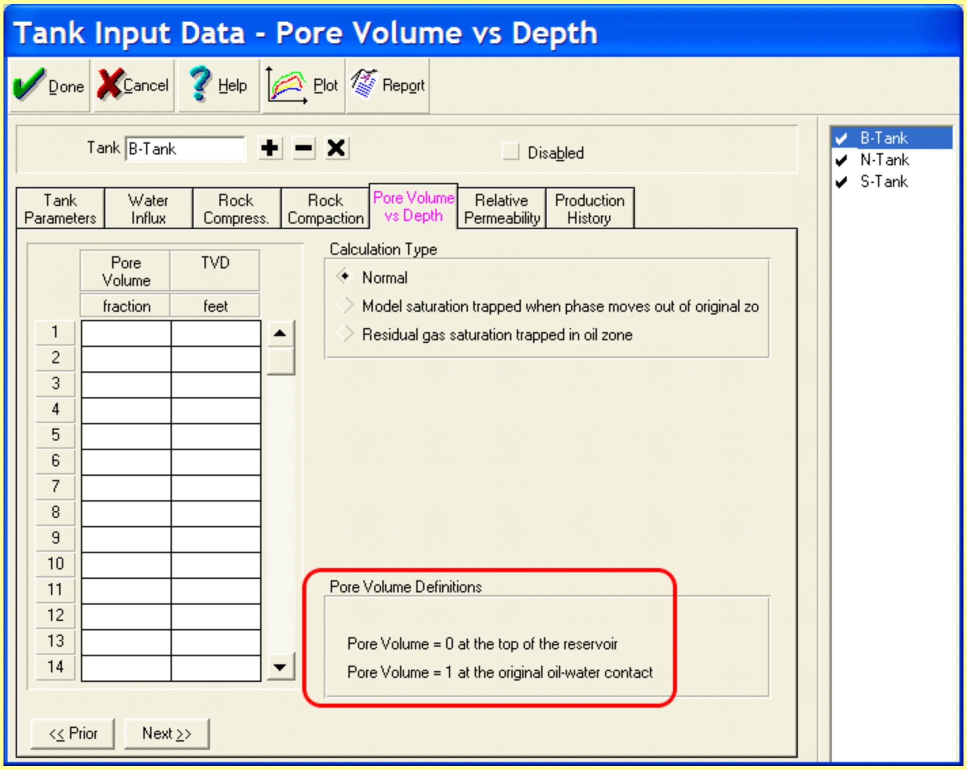
	If the objective is to take into account the saturation of the gas phase left behind as the water encroaches into the gas reservoir, then this can be taken into account using the SWEEP EFFICIENCY defined in the Relative Permeability tab.
Pore Volume vs. Depth For Gas/condensate Reservoirs	**Above GOC:** Pore Volume Fraction = (pore volume from top of gas cap to the depth of interest)/ (total gas cap pore volume) **Below GOC:** Pore Volume Fraction = 1.0 + (pore volume from top of oil leg to depth of interest)/ (total oil leg volume) For example, for the case below:  8000' TOP 2 MMRB (12.9%) 8120' 3 MMRB (19.4%) 8500' GOC 0.5 MMRB (3.2%) 8600' WOC 10 MMRB (64.5%) 9000' Total gas cap pore volume = 5 MMRB Total oil leg pore volume = 0.5 MMRB Gas pore volume fraction at 8000' = 0.0 Gas pore volume fraction at 8120' from GOC = 2 / 5 = 0.4 Gas pore volume fraction at 8500' from GOC = 5 / 5 = 1.0

Oil pore volume fraction at 8600' = 1 + 0.5 / 0.5 = 2.0

So the PV vs. Depth table can be entered as:

PV	TVD
0.0	8000
0.4	8120
1.0	8500
2.0	8600

There are three calculation methods related to this option:


Tank Input Data - Pore Volume vs Depth
Done
Cancel
Help
Plot
Report
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
<< Prior
Next >>

Tank B-Tank

☐ Disabled

	Pore Volume	TVD
	fraction	feet
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		

Calculation Type

● Normal

○ Model saturation trapped when phase moves out of original zo

○ Residual gas saturation trapped in oil zone

Pore Volume Definitions

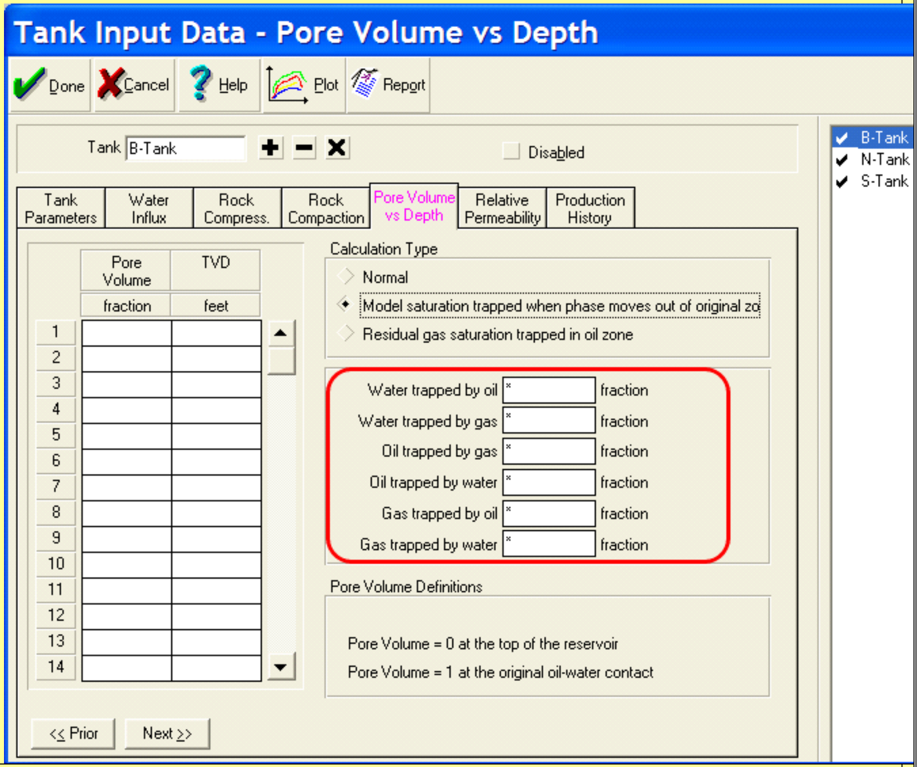
Pore Volume = 0 at the top of the reservoir

Pore Volume = 1 at the original oil-water contact

✓ B-Tank
✓ N-Tank
✓ S-Tank

Calculation Type

Normal	The method of calculating the fluid contacts depends on the fluid t of the reservoir. In each case we calculate the pore volume swep the appropriate phase. We then use the pore volume vs. depth ta to calculate the corresponding depth
Model Saturation trapped when phase moves out	This method uses the same rules as the old method for the resi saturations of the phases in their original locations i.e. the Sgr in original gas cap and the Sor in the original oil leg. However, whe phase invades Pore Volume originally occupied by another pha then a given saturation can be set as trapped, i.e. left behind. This

of original zone	effectively be seen as "sweep efficiency" with a lot of flexibilit specifying the saturations trapped by each phase invading the p volume originally occupied by a different phase: 
Residual Gas saturation trapped in oil zone (oil tank only)	In the normal calculations, as soon as the pressure drops below bubble point, the gas saturation starts increasing immediately. If option is activated, then the gas will remain in the oil pore volume the critical gas saturation is reached. Any further gas evolving ou the oil will create a gas cap

Tank Input Data - Pore Volume vs Depth

Done
Cancel
Help
Plot
Report
Tank B-Tank
☐ Disabled
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
Pore Volume fraction
TVD feet
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Water trapped by oil fraction
Water trapped by gas fraction
Oil trapped by gas fraction
Oil trapped by water fraction
Gas trapped by oil fraction
Gas trapped by water fraction
<< Prior
Next >>
✓ B-Tank
✓ N-Tank
✓ S-Tank

Calculation Type

○ Normal

● Model saturation trapped when phase moves out of original zo

○ Residual gas saturation trapped in oil zone

Pore Volume Definitions

Pore Volume = 0 at the top of the reservoir

Pore Volume = 1 at the original oil-water contact

2.12.3.2D-2 Standard Fluid Contact Calculations

The method of calculating the fluid contacts depends on the fluid type of the reservoir. In each case we calculate the pore volume swept by the appropriate phase. We then use the pore volume vs. depth table to calculate the corresponding depth.

In all cases the Sgr, Swc and Sor are taken from the relative permeability curves entered in the tank dialogue. If Stone's correction is not used then Sorw = Sorg = Sor.

The hysteresis option is not taken into account in these calculations.

Oil Reservoir	**(normal method)** In this method we assume that the Sgr always remains in the original gas cap. So if the oil sweeps into the original gas cap, the Sgr will be bypassed thus

decreasing the GOC.
Similarly if the gas moves into the original oil zone, we assume that Sorg is left behind the gas front so the GOC will increase more quickly.
If the water moves into the original oil zone, the water will leave the Sorw behind the water front.
In all cases the Swc is assumed to be evenly distributed throughout the reservoir thus reducing the sweepable volume.
The sweep efficiencies can be used to further increase the amount of saturations trapped behind the moving fronts.

For this option the saturations are defined with respect to the total reservoir i.e. the original oil leg and gas cap.
We first calculate the PV fraction swept by water for the current Sw. This calculation assumes that the WOC does not rise above the original GOC so we only consider the residual oil.
We assume the connate water Swc is distributed evenly throughout the reservoir. So the current movable water is Sw-Swc.
The residual oil saturation is Sorw. The Sorw is assumed to be left behind the water front. So the maximum possible movable volume is 1-Swc-Sorw.
So the water swept pore volume fraction would normally be:
$PVw = (Sw - Swc) / (1 - Swc - Sorw)$
However in addition the water sweep efficiency (Sew) can be used to further increase the amount of oil trapped by the water front thus increasing the water swept PV fraction. So:
$PVw = (Sw - Swc) / [(1 - Swc - Sorw)*Sew$

We also calculate the current PV fraction of the gas given the current Sg and the initial Sg (Sgi). The gas may have swept into the original oil zone or the oil may have swept into the original gas cap.

If the gas has swept into the original oil zone:
There is no initial gas in the original oil zone so the current gas that has swept into the original oil zone is just Sg - Sgi.
The residual oil saturation is Sorg. The Sorg is assumed to be left behind the gas front. So the maximum possible movable volume is 1-Swc-Sorg.
So the gas swept pore volume fraction would normally be:
$PVg = (Sg - Sgi) / (1 - Swc - Sorg)$
In addition the gas sweep efficiency (SEg) can be used to further increase the amount of oil trapped by the gas front thus increasing the gas swept PV fraction. So:
$PVg = (Sg - Sgi) / [(1 - Swc - Sorg)*SEg$
Finally we add the original gas saturation to get the total PVg:
$PVg = (Sg - Sgi) / [(1 - Swc - Sorg)*SEg + Sgi / (1 - Swc)$

If the gas has swept into the original gas cap:
There is no initial oil in the original gas cap so the current oil that has swept into the original gas cap is Sgi - Sg.

	The residual gas saturation is Srg. The Srg is assumed to be left behind the oil front. So the maximum possible movable volume is 1-Swc-Srg. So the oil swept pore volume fraction in the original gas cap would normally be: PVo = (Sgi - Sg) / (1 - Swc - Srg) However in addition the gas sweep efficiency (SEg) can be used to further increase the amount of gas trapped by the oil front thus increasing the gas swept PV fraction (technically this should be labeled the 'oil sweep efficiency'): PVo = (Sgi - Sg) / (1 - Swc - Srg)*SEg Finally we subtract from the original gas saturation to get the total PVg: PVg = Sgi / (1 - Swc) - PVo
Oil Reservoir	**(if gas cap production option is off)** In this method if the gas moves into the original oil zone, we assume that Sorg is left behind the gas front. So the GOC will increase more quickly. If the water moves into the oil zone, the water will leave the Sorw behind the water front. In all cases the Swc is assumed to be evenly distributed throughout the reservoir thus reducing the sweepable volume. The sweep efficiencies can be used to further increase the amount of saturations trapped behind the moving fronts. For this option the saturations are defined with respect to the original oil zone. We first calculate the PV fraction swept by water for the current Sw. We assume the connate water Swc is distributed evenly throughout the reservoir. So the current movable water is Sw-Swc. The residual oil saturation is Sorw. The Sorw is assumed to be left behind the water front. So the maximum possible movable volume is 1-Swc-Sorw. So the water swept pore volume fraction would normally be: PVw = (Sw - Swc) / (1 - Swc - Sorw) However in addition the water sweep efficiency (Sew) can be used to further increase the amount of oil trapped by the water front thus increasing the water swept PV fraction. So: PVw = (Sw - Swc) / [(1 - Swc - Sorw)*Sew We also calculate the PV fraction swept by the gas given the current Sg. There is no initial gas in the original oil zone so the current movable gas is just Sg. The residual oil saturation is Sorg. The Sorg is assumed to be left behind the gas front. So the maximum possible movable volume is 1-Swc-Sorg. So the gas swept pore volume fraction would normally be: PVg = Sg / (1 - Swc - Sorg) However in addition the gas sweep efficiency (SEg) can be used to further increase the amount of oil trapped by the gas front thus increasing the gas swept PV fraction. So: PVg = Sg / [(1 - Swc - Sorg)*SEg
Gas Reservoir	**(normal method)** In this case we assume that the Sgr and Swc are distributed evenly throughout

	the reservoir and remain there through the life of the reservoir. So these residual saturations will reduce the sweepable volume. The sweep efficiencies can be used to further increase the amount of saturations trapped behind the moving fronts. We calculate the PV fraction swept by water for the current Sw. We assume the connate water Swc is distributed evenly throughout the reservoir. So the current movable water is Sw-Swc. The residual gas saturation is Sgr. The Sgr is assumed to be left behind the water front. So the maximum possible movable volume is 1-Swc-Sgr. So the water swept pore volume fraction would normally be: PVw = (Sw - Swc) / (1 - Swc - Sgr) However in addition the water sweep efficiency (Sew) can be used to further increase the amount of gas trapped by the water front thus increasing the water swept PV fraction. So: PVw = (Sw - Swc) / [(1 - Swc - Sgr)*Sew
Gas Reservoir	**(using Gas Storage option)** In this case we assume that the Sgr and Swc are distributed evenly throughout the reservoir and remain there through the life of the reservoir. So these residual saturations will reduce the sweepable volume. The sweep efficiencies can be used to further increase the amount of saturations trapped behind the moving fronts. For gas storage we calculate the PV fraction swept by gas for the current Sg (since gas is normally injected into the water). We assume the residual gas Sgr is distributed evenly throughout the reservoir. So the current movable gas is Sg-Sgr. The connate water saturation Swc is assumed to be left behind the water front. So the maximum possible movable volume is 1-Sgr-Swc. So the gas swept pore volume fraction would normally be: PVg = (Sg - Sgr) / (1 - Sgr - Swc) However in addition the gas sweep efficiency (SEg) can be used to further increase the amount of water trapped by the gas front thus increasing the gas swept PV fraction. So: PVg = (Sg - Sgr) / [(1 - Sgr - Swc)*SEg This method means that the Sgr entered in the tank relative permeability curves should be the Sg in the tank at the start of the gas storage production/injection cycle. In other words, it should correspond to the original gas in place entered in the tank parameters dialogue
Condensate Reservoir	In this case we assume that the Sgr and Swc are distributed evenly throughout the reservoir and remain there through the life of the reservoir. So these residual saturations will reduce the sweepable volume. The sweep efficiencies can be used to further increase the amount of saturations trapped behind the moving fronts. We first calculate the PV fraction swept by water for the current Sw. We assume that any drop out oil is 100% sweepable.

	We assume the connate water Swc is distributed evenly throughout the reservoir. So the current movable water is Sw-Swc. The residual gas saturation is Sgr. The Sgr is assumed to be left behind the water front. So the maximum possible movable volume is 1-Swc-Sgr. So the water swept pore volume fraction would normally be: PVw = (Sw - Swc) / (1 - Swc - Sgr) However in addition the water sweep efficiency (Sew) can be used to further increase the amount of gas trapped by the water front thus increasing the water swept PV fraction. So: PVw = (Sw - Swc) / [(1 - Swc - Sgr)*Sew Then we calculate the PV fraction of the gas left in the reservoir: PVw = (Sg - Sgr) / (1 - Swc - Sgr)
Condensate Reservoir	**(using material balance with an initial oil leg)** In this method we assume that the Sor always remains in the original oil leg. So if the gas or water sweeps into the original oil leg, the Sor will be bypassed. Similarly if the oil moves into the original gas cap, we assume that Sgr is left behind the oil front. So the GOC will increase more quickly. In all cases the Swc is assumed to be evenly distributed throughout the reservoir thus reducing the sweepable volume. The sweep efficiencies can be used to further increase the amount of saturations trapped behind the moving fronts. For this option the saturations are defined with respect to the total reservoir i.e. the original oil leg and gas cap. We first calculate the PV fraction swept by water for the current Sw. This calculation assumes that the WOC does not rise above the original GOC so we only consider the residual oil. We assume the connate water Swc is distributed evenly throughout the reservoir. So the current movable water is Sw-Swc. The residual oil saturation is Sor. The Sor is assumed to be left behind the water front. So the maximum possible movable volume is 1-Swc-Sor. So the water swept pore volume fraction would normally be: PVw = (Sw - Swc) / (1 - Swc - Sor) In addition, the water sweep efficiency (Sew) can be used to further increase the amount of oil trapped by the water front thus increasing the water swept PV fraction: PVw = (Sw - Swc) / [(1 - Swc - Sor)*Sew We also calculate the current PV fraction of the gas given the current Sg and the initial Sg (Sgi). The gas may have swept into the original oil zone or the oil may have swept into the original gas cap. If the gas has swept into the original oil zone: There is no initial gas in the original oil zone so the current gas that has swept into the original oil zone is just Sg - Sgi. The residual oil saturation is Sorg. The Sorg is assumed to be left behind the

	gas front. So the maximum possible movable volume is 1-Swc-Sor. So the gas swept pore volume fraction would normally be: PVg = (Sg - Sgi) / (1 - Swc - Sor) In addition the gas sweep efficiency (SEg) can be used to further increase the amount of oil trapped by the gas front thus increasing the gas swept PV fraction: PVg = (Sg - Sgi) / [(1 - Swc - Sor)*SEg Finally, we add on the original gas saturation to get the total PVg: PVg = (Sg - Sgi) / [(1 - Swc - Sor)*SEg + Sgi / (1 - Swc) If the gas has swept into the original gas cap: There is no initial oil in the original gas cap so the current oil that has swept into the original gas cap is Sgi - Sg. The residual gas saturation is Srg. The Srg is assumed to be left behind the oil front. So the maximum possible movable volume is 1-Swc-Srg. So the oil swept pore volume fraction in the original gas cap would normally be: PVo = (Sgi - Sg) / (1 - Swc - Srg) In addition the gas sweep efficiency (SEg) can be used to further increase the amount of gas trapped by the oil front thus increasing the gas swept PV fraction (technically is should be labeled the oil sweep efficiency): PVo = (Sgi - Sg) / (1 - Swc - Srg)*SEg Finally we subtract from the original gas saturation to get the total PVg: PVg = Sgi / (1 - Swc) - PVo

2.12.3.3D-3 Trapped Saturation Fluid Contact Calculations

The new method uses the same rules as the old method for the residual saturations of the phases in their original locations i.e. the Sgr in the original gas cap and the Sor in the original oil leg. These rules are:

Oil Reservoir	**(normal method)** In this method we assume that the Sgr always remains in the original gas cap. So if the oil sweeps into the original gas cap, the Sgr will be bypassed thus decreasing the GOC. Similarly if the gas moves into the original oil zone, we assume that Sorg is left behind the gas front. So the GOC will increase more quickly. If the water moves into the original oil zone, the water will leave the Sorw behind the water front. In all cases the Swc is assumed to be evenly distributed throughout the reservoir thus reducing the sweepable volume. The sweep efficiencies can be used to further increase the amount of saturations trapped behind the moving fronts

Oil **Reservoir**	**(if gas cap production option is off)** In this method if the gas moves into the original oil zone, we assume that Sorg is left behind the gas front. So the GOC will increase more quickly. If the water moves into the oil zone, the water will leave the Sorw behind the water front. In all cases the Swc is assumed to be evenly distributed throughout the reservoir thus reducing the sweepable volume. The sweep efficiencies can be used to further increase the amount of saturations trapped behind the moving fronts
Gas Reservoir	**(normal method)** In this case we assume that the Sgr and Swc are distributed evenly throughout the reservoir and remain there through the life of the reservoir. So these residual saturations will reduce the sweepable volume. The sweep efficiencies can be used to further increase the amount of saturations trapped behind the moving fronts
Gas Reservoir	**(using Gas Storage option)** In this case we assume that the Sgr and Swc are distributed evenly throughout the reservoir and remain there through the life of the reservoir. So these residual saturations will reduce the sweepable volume. The sweep efficiencies can be used to further increase the amount of saturations trapped behind the moving fronts
Condensate Reservoir	In this case we assume that the Sgr and Swc are distributed evenly throughout the reservoir and remain there through the life of the reservoir. So these residual saturations will reduce the sweepable volume. The sweep efficiencies can be used to further increase the amount of saturations trapped behind the moving fronts
Condensate Reservoir	**(using material balance with an initial oil leg)** In this method we assume that the Sor always remains in the original oil leg. So if the gas or water sweeps into the original oil leg, the Sor will be bypassed. Similarly if the oil moves into the original gas cap, we assume that Sgr is left behind the oil front. So the GOC will increase more quickly. In all cases the Swc is assumed to be evenly distributed throughout the reservoir thus reducing the sweepable volume. The sweep efficiencies can be used to further increase the amount of saturations trapped behind the moving fronts. NOTE: In addition this method also allows trapped phases to be modelled after moving out of their original zone

Consider an oil reservoir where the original gas cap moves into the original oil zone because the oil leg is depleted. Then later in the life of the reservoir the gas cap is produced so that the oil moves back into the gas cap. With the standard method, all of the gas that moved into the original oil zone will be swept back into the gas cap. This method allows the user to model a situation in which some of the gas that moved into the original oil zone is trapped when the oil sweeps back up to the original gas-oil contact.

Note that if the oil sweeps into the original gas cap, it will still bypass the Sgr as would happen with the standard method.

With this method, we have generalized the calculation. So if any phase A moves out of its original zone, and is then swept out again by another phase B, the saturation of the phase A that is bypassed by phase B may be entered.

When this option is selected the user will be asked to enter one or more of the following inputs depending on the reservoir type:

Water Trapped by Oil	Water trapped when water moves into original oil/gas zone and is then swept by oil
Water Trapped by Gas	Water trapped when water moves into original oil/gas zone and is then swept by gas
Oil Trapped by Gas	Oil trapped when oil moves into original gas cap and is then swept by gas
Oil Trapped by Water	Oil trapped when oil moves into original gas cap and is then swept by water
Gas Trapped by Oil	Gas trapped when gas moves into original oil leg and is then swept by oil
Gas Trapped by Water	Gas trapped when gas moves into original oil leg and is then swept by water

Note: For trapped water saturations, the saturation should include the connate water saturation. E.g. if Swc=0.1 but another S=0.1 is trapped by a sweeping phase, then enter a total trapped water saturation of 0.2.

Example

Figure 1

This shows the oil reservoir at initial conditions

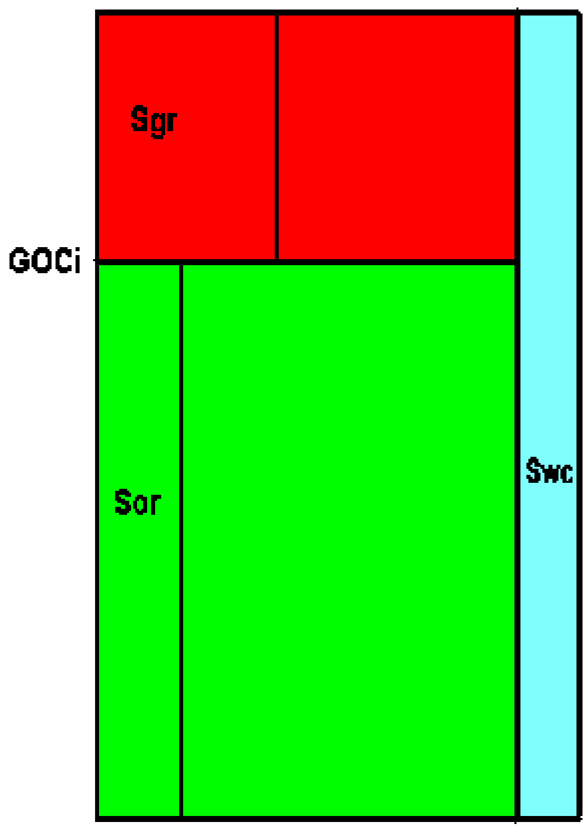


Figure 2

Some oil has been produced so the Sg increases and the gas has moved into the original oil leg. The Swc and Sor are left behind the gas front thus increasing the GOC.

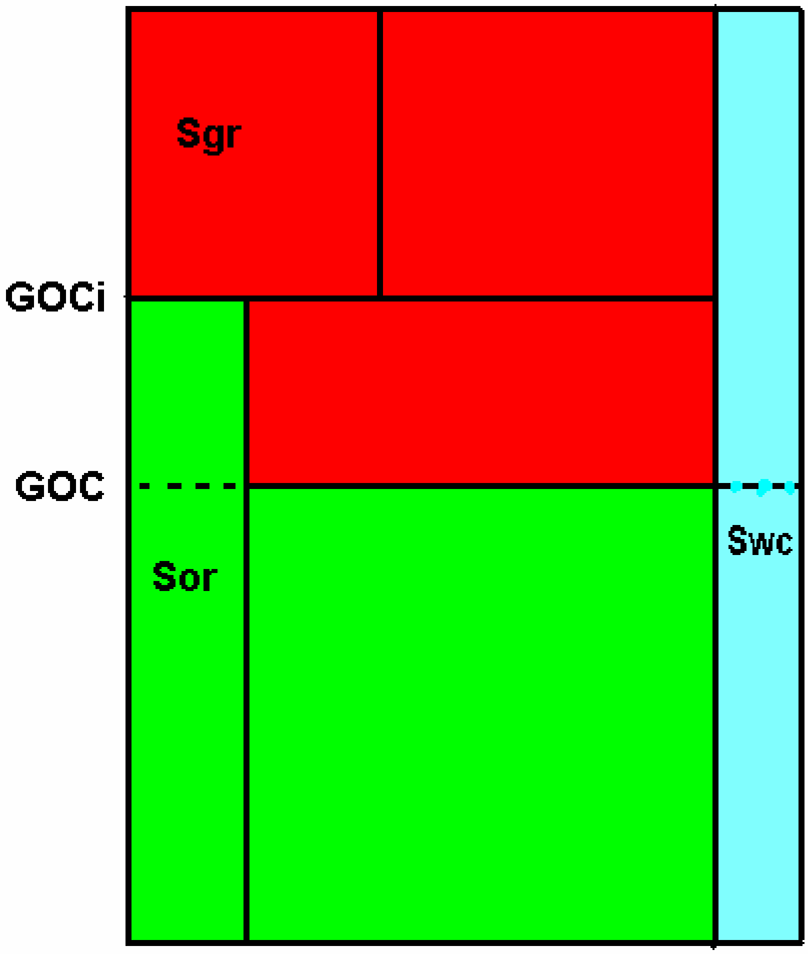


Figure 3

Gas is now being produced so the Sg decreases and the So increases. Therefore the oil moves upwards in the reservoir. Now in this case we have entered the value for the gas trapped by oil (Sgro). So as the oil moves up, the Sgro is trapped behind the GOC.

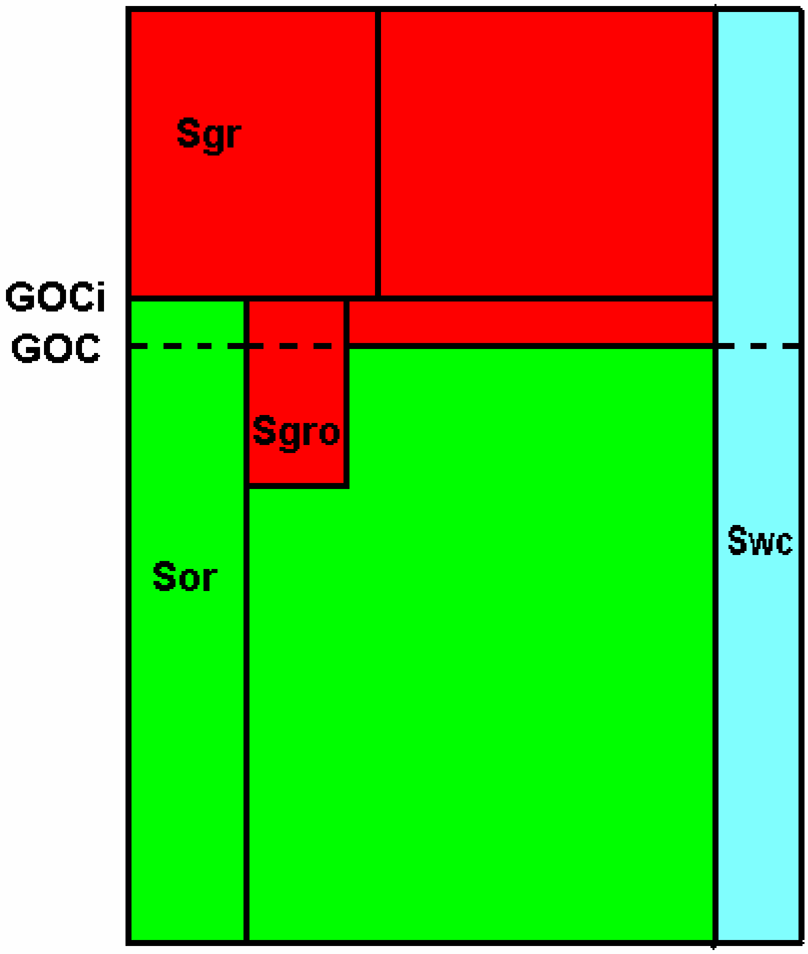
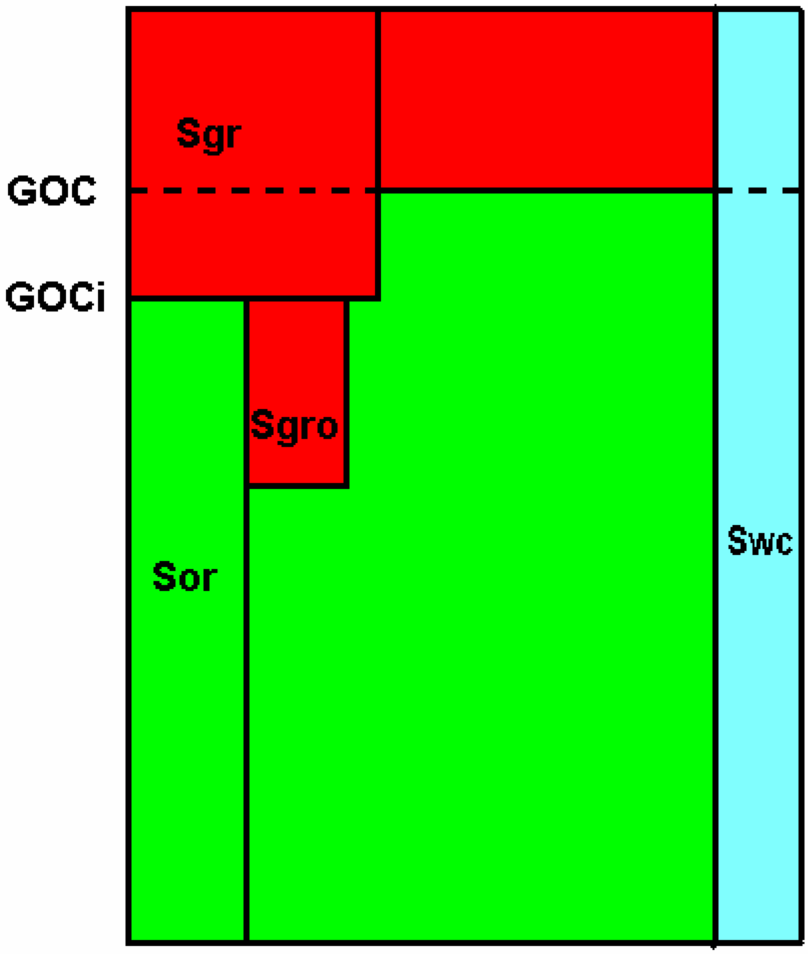

Sgr
GOCi
GOC
Sgro
Sor
Swc

Figure 4

We continue to produce gas so the So continues to increase. Now the GOC moves into the original gas cap. In the original gas cap the GOC will bypass the Sgr as well as the Swc.

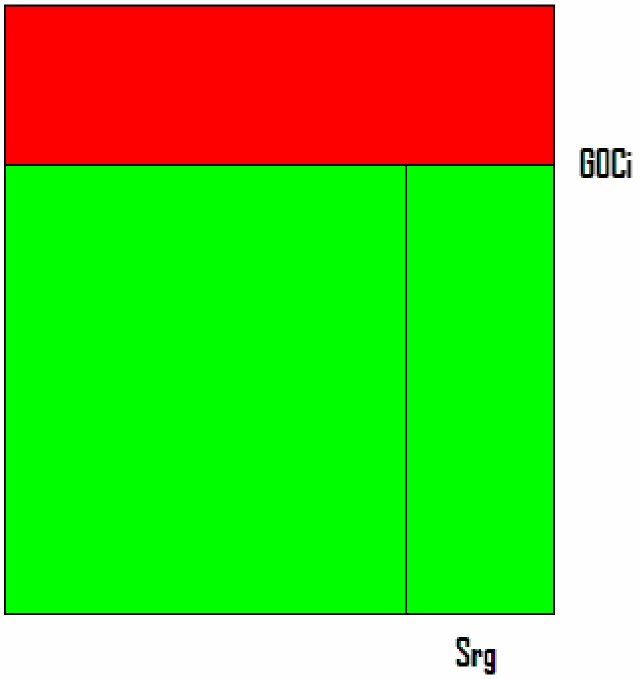


2.12.3.4D-4 Trapped Saturation Fluid Contact Calculations

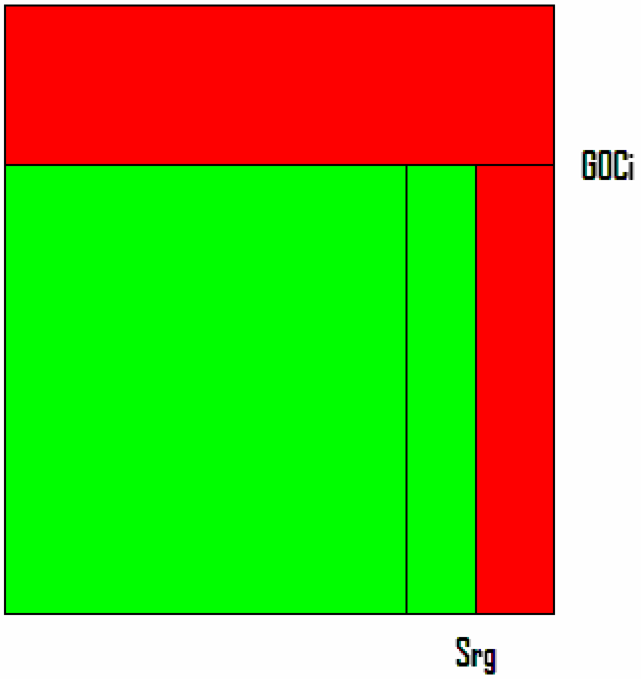
This method is only available for oil tanks. It is the same as the standard method except that when gas bubbles out of the oil, the gas is trapped in the oil zone up to the residual gas saturation.

Once the gas saturation in the oil zone reaches the residual gas saturation, the extra gas will move directly into the gas cap.

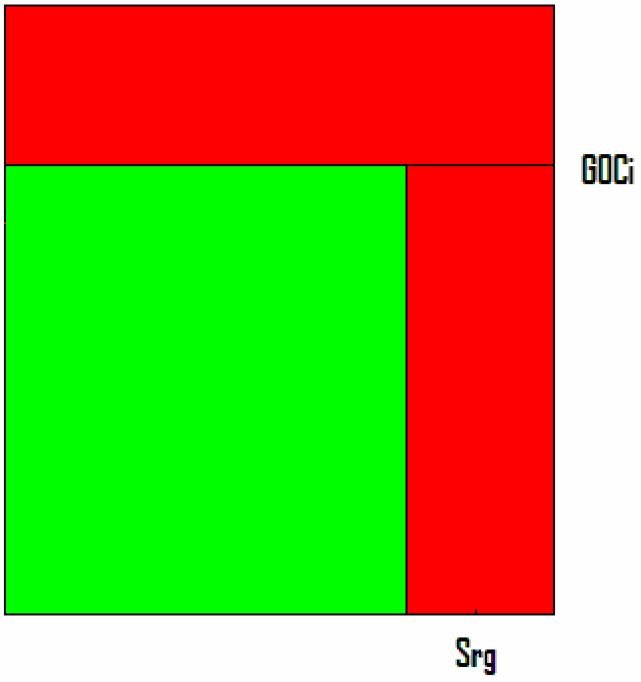
At T_0 - initial reservoir conditions



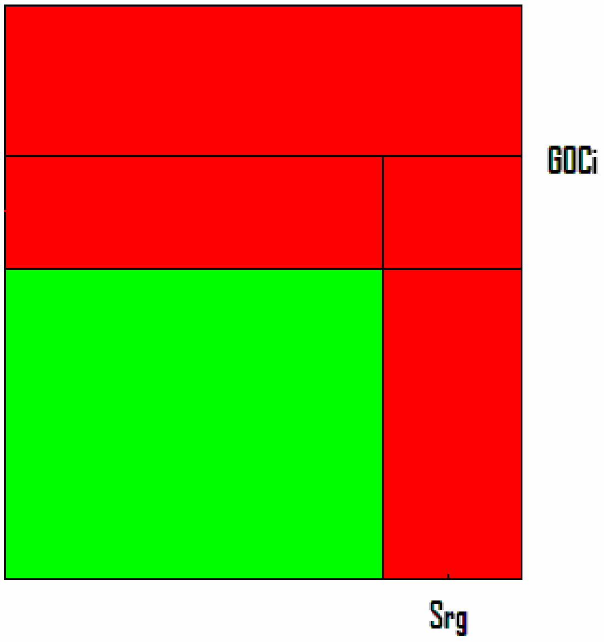
At T_1 – Gas in oil zone is still less than Srg so remains in oil zone.



At T_2 – Gas in oil zone reaches Srg.



At T_3 – New solution gas now moves into secondary gas cap resulting in rapidly increasing GOC.



2.12.4 D- Trouble Shooting Guide

This appendix describes some of the common problems experienced and questions asked by users of **MBAL**.

2.12.4.1 E-1 Prediction not Meeting Constraints

Question:
The production prediction calculation is not meeting the constraints that I entered in the **Production Prediction-Production and Constraints** dialogue.

Answer:
The only method available in **MBAL** to control the production (and thus meet constraints) is by modification of the manifold pressure.

If the constraint entered by the user is not being adhered to, the following steps define possible causes that could be investigated:

- In the well definition-outflow tab dialogue, check that the constant FBHP is not in use. If it is, **MBAL** has no way to control the production so cannot meet constraints. In this,Tubing Performance Curves should be used to model the well.
- Also in the well definition-outflow tab dialogue, ensure that 'Extrapolate TPC's' has been switched on for all of the wells. If not, then **MBAL** cannot control the production if the manifold pressure goes outside of the range of Tubing Performance Curves. It may also be necessary to regenerate theTubing Performance Curves with a wider range of manifold pressures to ensure accuracy.
- Also in the well definition-outflow tab dialogue, check that the Tubing Performance Curves have more than one manifold pressure.

2.12.4.2 E-2 Production Prediction Fails

Question:
In the **Production Prediction-Run Prediction**, I clicked on the **Calc** button but immediately got a message box saying that the "The calculation is complete" and no results were displayed.

Answer:
There are a number of reasons why this may happen but the immediate reason is usually that the prediction is stopping prematurely because the rate has dropped to zero. Analysis for this becomes more complex due to the lack of data.

The first step is to force the calculation to keep going.
Go back to **Production Prediction-Prediction Setup** and change the **Prediction End** to **User Defined** and enter a date some time after the start of the prediction. Now rerun the prediction and it should produce results of some sort. It should now be possible to diagnose why the calculation fails - firstly by examining the well results.

2.12.4.3E-3 Pressures in the Prediction are increasing (With No Injection)

Question:
In history simulation or production prediction the pressure is increasing but I do not have any injection.

Answer:
Although there are a number of reasons for this problem the most common reason is errors in the PVT input. Use the **PVT-Calculator** option to calculate properties and verify each one in turn. In particular, check the Bo and/or Bg as these are crucial to the material balance calculation.

2.12.4.4E-4 Reversal in the Analytic Plot

Question:
In history matching-analytic plot, the simulated data is going backwards or even looping - why is this happening?

Answer:
For the single tank, the analytic plot calculates the primary phase rate from the input tank pressure and non-principal phase rates (as well as the reset of the tank description). For example, for an oil tank, it will calculate the cumulative oil rate from the input tank pressure, water production, gas production, water injection and gas injection. The calculation is done this way because it is much faster than calculating the pressure from all the rates - and speed is critical when doing a regression.

This means that if there is an error in the estimates of the input data, **MBAL** may only be able to maintain the input tank pressure by re-injecting oil. For example, imagine that the aquifer size has been underestimated. **MBAL** will have to re-inject oil to compensate for the lack of aquifer.

To summarise, if reversal is observed in the simulated data, either the estimates of the tank parameters are in error or there are errors in the production data.

2.12.4.5E-5 Difference between History Simulation and Analytic Plot

Question:
I have done a match in the analytic plot and get a good visual match in the final pressure. I then did a history simulation but get a poor match on the final pressure.

Answer:
For the single tank, the analytical plot calculates the primary phase rate from the input tank pressure and non-principal phase rates. For example, for an oil tank, it will calculate the cumulative oil rate from the input tank pressure, water production, gas production, water injection and gas injection. The calculation is done this way because it is much faster than calculating the pressure from all the rates - and speed is critical when carrying out a regression.

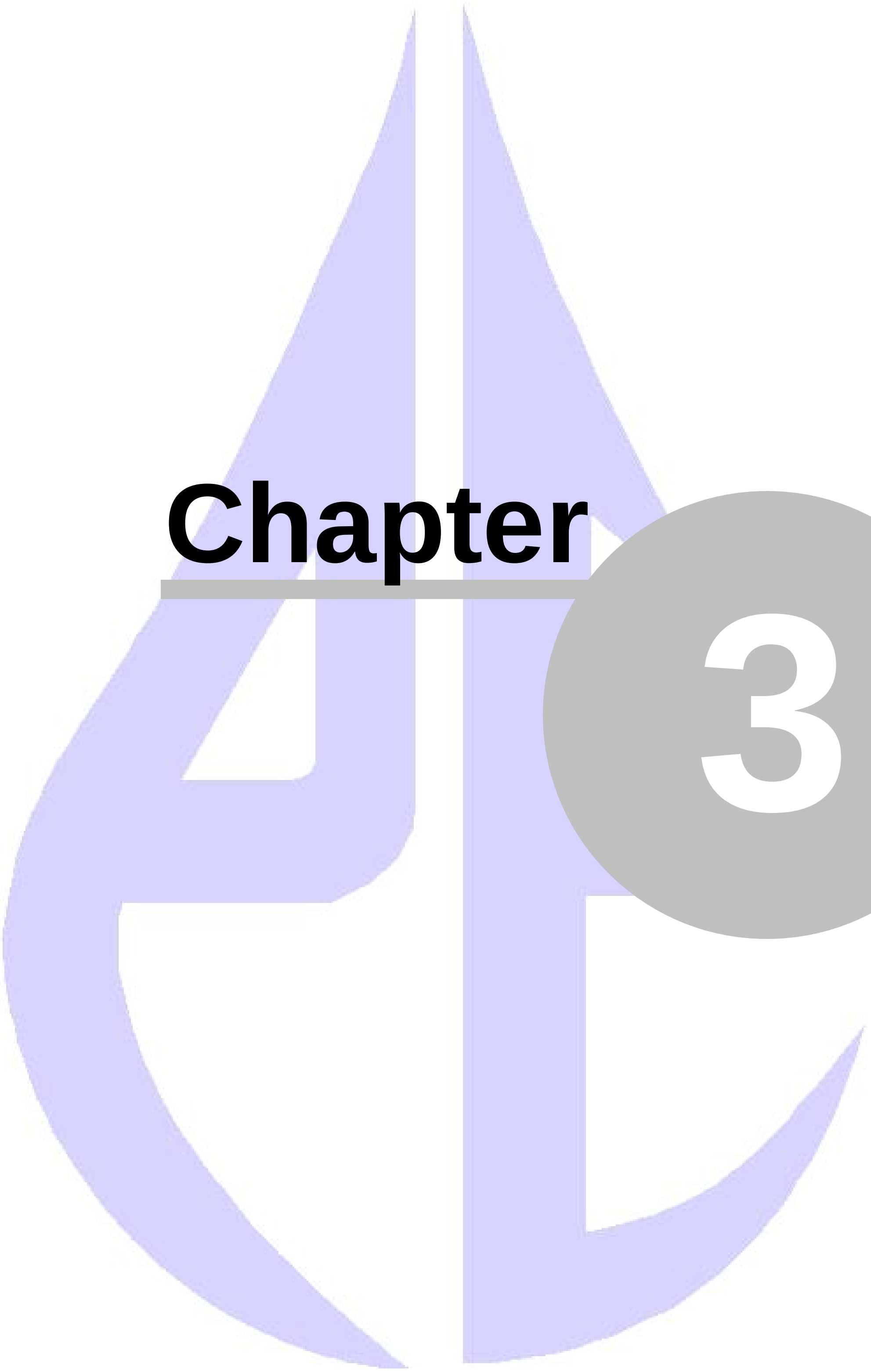
Traditionally, one tends to look for the difference in the vertical separation between the input and simulated data when assessing the quality of a match. However, as the cumulative oil is being investigated, the horizontal separation between the input and simulated data is the main point of focus. A match can appear to be of good quality if looking at the vertical separation only but actually be relatively poor if examined in the horizontal direction.

The history simulation does the reverse calculation - it calculates the tank pressure from the various input rates. Therefore the vertical difference between the tank history pressure and simulated pressure should be investigated when assessing the quality of the match.
v

2.12.4.6E-6 Dialogues Are Not Displayed Correctly

Question:
Some of the dialogues in ***MBAL*** are not displayed correctly. In particular, they are too big for the screen so the buttons are not visible.

Answer:
This problem is due to screen resolution. The simplest fix is to change the **Screen Resolution** in ***MBAL***. Select the **File – Preferences** menu item in ***MBAL*** and try each of the options in the **Screen Resolution** combo box in turn until one has been that displays the dialogues correctly.



Chapter

3

3 Examples Guide

3.1 Quick Start Guide on Material Balance tool

The objective of this example is to demonstrate the basic functionality of **MBAL** in terms of history matching options and performing predictions. The following topics will be described:

- Quality-checking the available data. This quality check is based on what is physically possible and focussed towards determining inconsistencies between data and physical reality.
- History matching procedure to determine the OOIP and possible aquifer size.
- Prepare the history matched model for forecasts (Fractional Flow Matching)
- Creating a well model in **MBAL** upon which the forecast will be based

3.1.1 Data Available

PVT data

(@ 250 deg F)

- Bubble point (P_b) = 2200 psig
- Solution GOR = 500 SCF/STB
- FVF@ $P_{b\,=}$ 1.32 RB/STB
- Oil Visc.@ $P_{b\,=}$ 0.4 cP
- Oil gravity = 39 API
- Gas grav. = 0.798
- Water Salinity = 100,000 PPM

Production data

This data is contained in an Excel file OILRES1.XLS. Later in this chapter a description on how to transfer the data from Excel into ***MBAL*** will be provided.

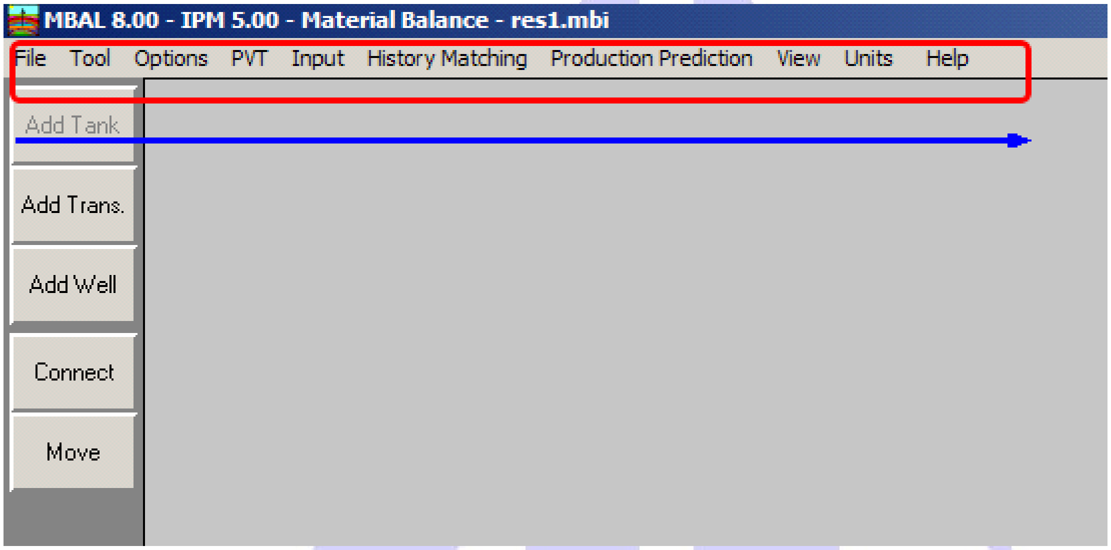
Well Data

Once the history matching is finished, data (IPR and VLP) will be provided so that a forecast can be made based on this information

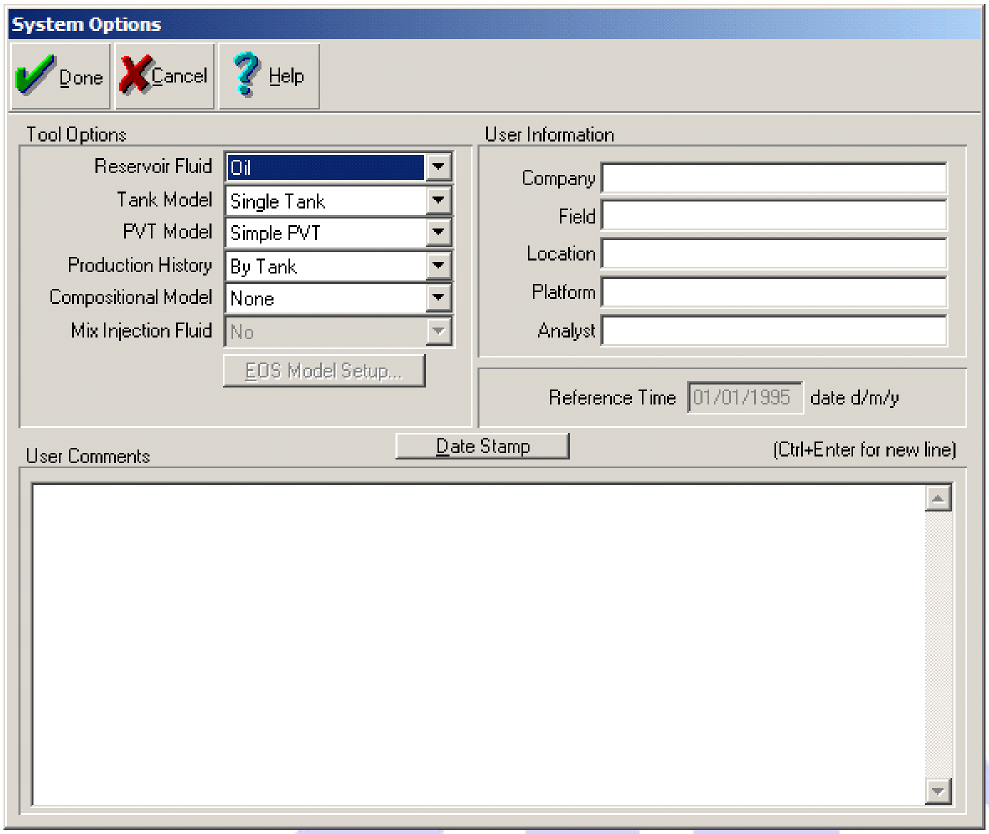
➲ **Please note that a well model is not necessary for performing forecasts in MBAL. However, it provides a more realistic basis on which the forecasts can be made compared to the simpler fixed withdrawal options. Of course, the most realistic profile will be obtained if the effects of the surface network** are modelled by importing the MBAL model in GAP

3.1.2 Setting up the Basic Model

MBAL is set up in the same manner as the rest of the **IPM** tools; the required workflow to carry out a full reservoir model is simply obtained by moving from left to right across the screen and top to bottom for each selected heading.


MBAL 8.00 - IPM 5.00 - Material Balance - res1.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Add Tank
Add Trans.
Add Well
Connect
Move

- Start **MBAL** and select the menu option **File | New**.
- On the menu bar go to **Tools** and click on **Material Balance**.
- On the menu bar go to **Options** and following screen appears. The following options can be selected:


System Options
Done
Cancel
Help
EOS Model Setup...
Date Stamp

Tool Options

Reservoir Fluid: Oil
Tank Model: Single Tank
PVT Model: Simple PVT
Production History: By Tank
Compositional Model: None
Mix Injection Fluid: No

User Information

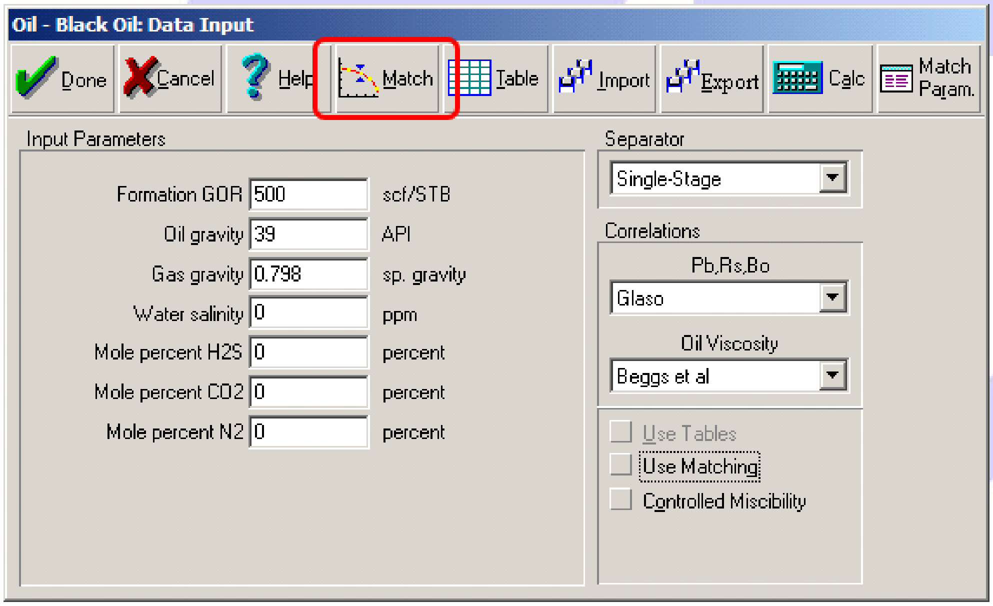
Company
Field
Location
Platform
Analyst

Reference Time 01/01/1995 date d/m/y

User Comments (Ctrl+Enter for new line)

In this screen, the fluid has been defined as oil. The production history will be entered by tank.

Progressing to **PVT | Fluid Properties** the following data can be entered:


Oil - Black Oil: Data Input
Done
Cancel
Help
Match
Table
Import
Export
Calc
Match Param.

Input Parameters

Formation GOR 500 scf/STB
Oil gravity 39 API
Gas gravity 0.798 sp. gravity
Water salinity 0 ppm
Mole percent H2S 0 percent
Mole percent CO2 0 percent
Mole percent N2 0 percent

Separator: Single-Stage

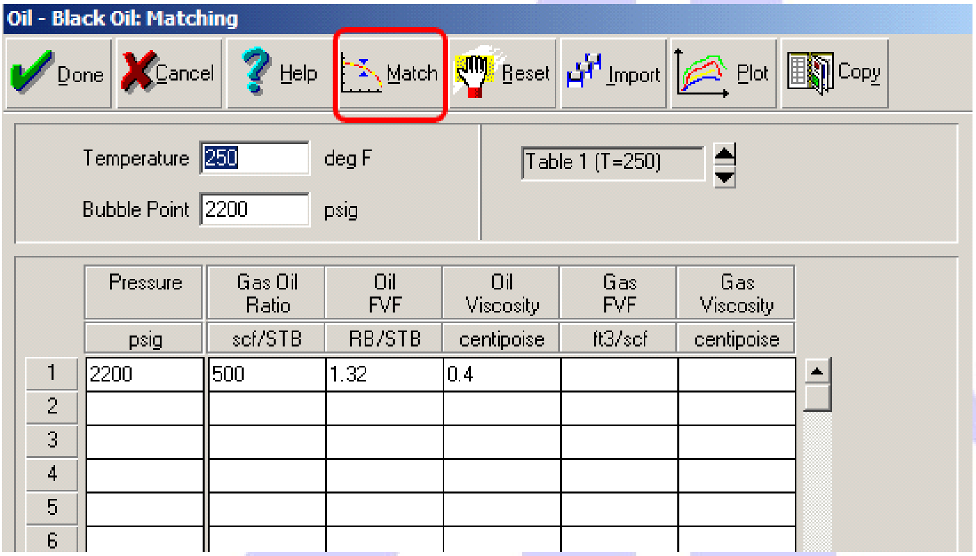
Correlations

Pb,Rs,Bo: Glaso
Oil Viscosity: Beggs et al

☐ Use Tables
☐ Use Matching
☐ Controlled Miscibility

In this section the black oil properties of the oil have been defined. The water salinity was also specified (allowing calculation of the water properties) and indicated that the produced gas has no CO2, H2S or N2 in it.

Since laboratory measured data for this fluid at bubble point conditions are available, these will be matched to the available correlations. The correlations that best match the fluid (require the least correction) will then be selected for use in the model. In the PVT input dialogue, press the **Match** button to invoke the screen where the match data can be entered:


Oil - Black Oil: Matching
Done
Cancel
Help
Match
Reset
Import
Plot
Copy

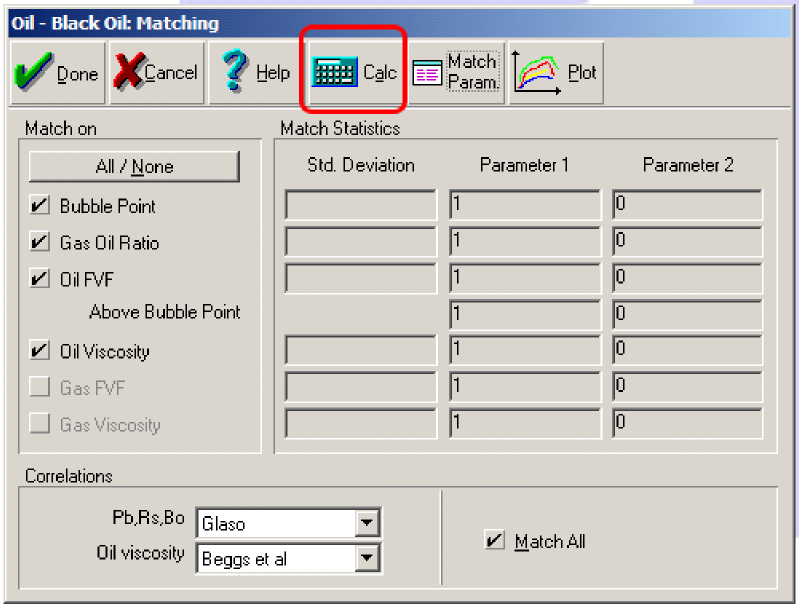
Temperature 250 deg F

Bubble Point 2200 psig

Table 1 (T=250)

	Pressure psig	Gas Oil Ratio scf/STB	Oil FVF RB/STB	Oil Viscosity centipoise	Gas FVF ft3/scf	Gas Viscosity centipoise
1	2200	500	1.32	0.4		
2						
3						
4						
5						
6						

After the data has been entered, clicking on **Match** will lead to the screen where the regression between correlations and measured data will be done:


Oil - Black Oil: Matching
Done
Cancel
Help
Calc
Match Param
Plot
All / None

Match on	Std. Deviation	Parameter 1	Parameter 2
☑ Bubble Point		1	0
☑ Gas Oil Ratio		1	0
☑ Oil FVF		1	0
Above Bubble Point		1	0
☑ Oil Viscosity		1	0
☐ Gas FVF		1	0
☐ Gas Viscosity		1	0

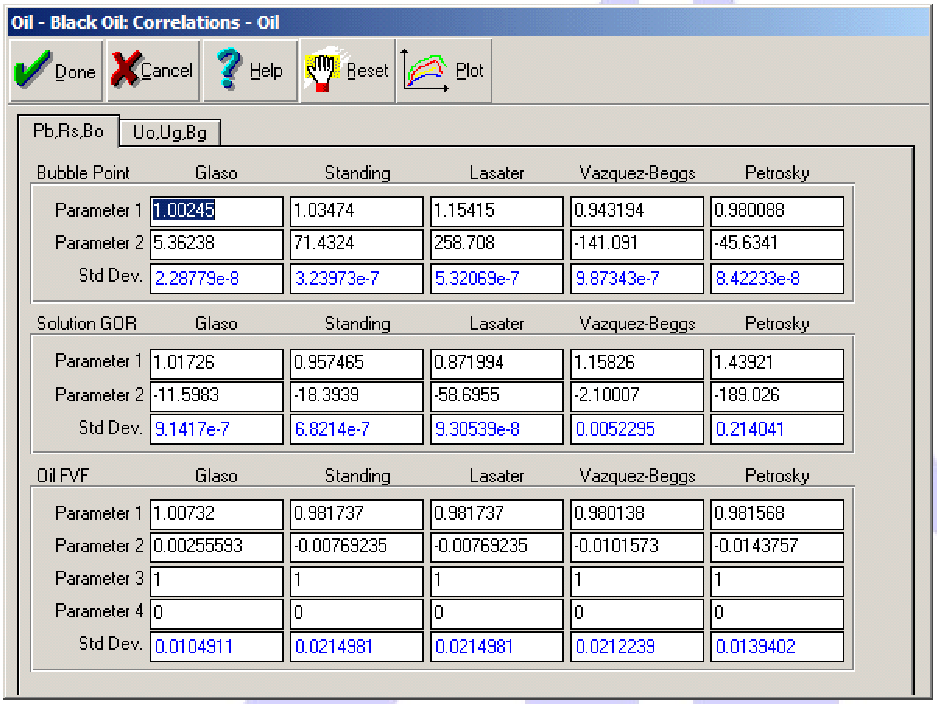
Correlations

Pb,Rs,Bo: Glaso

Oil viscosity: Beggs et al

☑ Match All

Once this is done, click the **Match Param** button to check the parameters of each of the correlations and select the one which requires the least correction. In this case, Glaso is selected for bubble point, GOR and FVF calculations; and Beggs for viscosity (Parameter 1 as close to 1 as possible and Parameter 2 as close to 0 as possible).



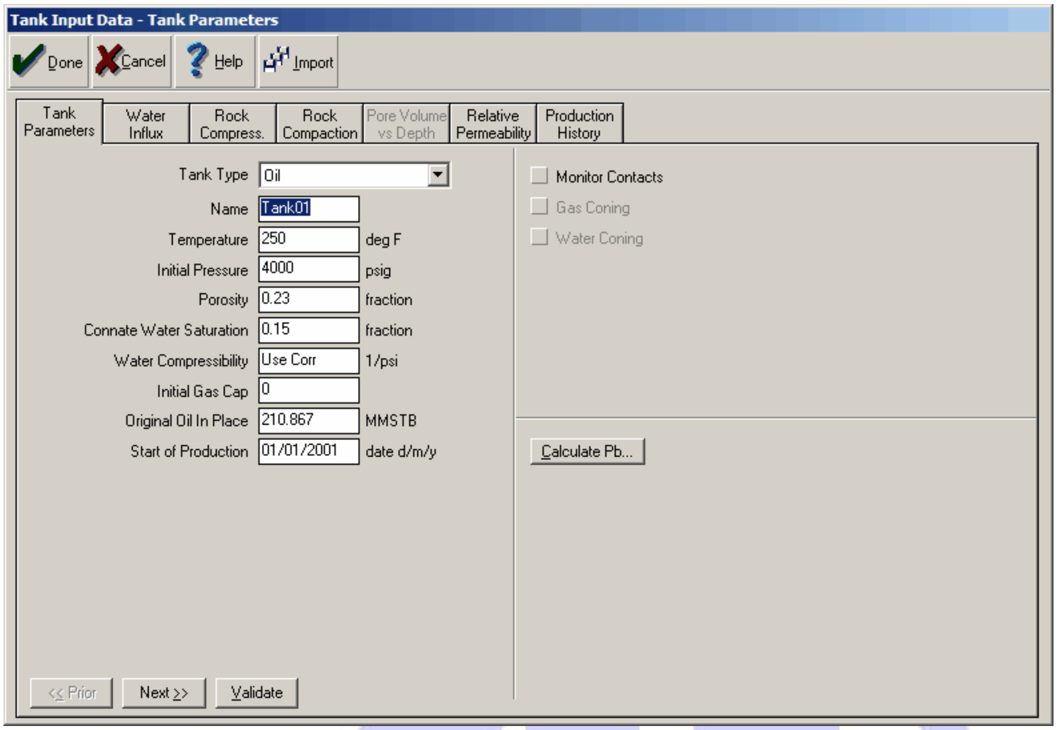
Bubble Point	Glaso	Standing	Lasater	Vazquez-Beggs	Petrosky
Parameter 1	1.00245	1.03474	1.15415	0.943194	0.980088
Parameter 2	5.36238	71.4324	258.708	-141.091	-45.6341
Std Dev.	2.28779e-8	3.23973e-7	5.32069e-7	9.87343e-7	8.42233e-8

Solution GOR	Glaso	Standing	Lasater	Vazquez-Beggs	Petrosky
Parameter 1	1.01726	0.957465	0.871994	1.15826	1.43921
Parameter 2	-11.5983	-18.3939	-58.6955	-2.10007	-189.026
Std Dev.	9.1417e-7	6.8214e-7	9.30539e-8	0.0052295	0.214041

Oil FVF	Glaso	Standing	Lasater	Vazquez-Beggs	Petrosky
Parameter 1	1.00732	0.981737	0.981737	0.980138	0.981568
Parameter 2	0.00255593	-0.00769235	-0.00769235	-0.0101573	-0.0143757
Parameter 3	1	1	1	1	1
Parameter 4	0	0	0	0	0
Std Dev.	0.0104911	0.0214981	0.0214981	0.0212239	0.0139402

At this stage, specifying the PVT properties of the fluid is finished. The next step is entering the initial data for the reservoir model.

In the main menu bar go to **Input | Tank Data**, and supply the following information:


Tank Input Data - Tank Parameters
Done
Cancel
Help
Import
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
Calculate Pb...
<< Prior
Next >>
Validate

Tank Type: Oil

Name: Tank01

Temperature: 250 deg F

Initial Pressure: 4000 psig

Porosity: 0.23 fraction

Connate Water Saturation: 0.15 fraction

Water Compressibility: Use Corr 1/psi

Initial Gas Cap: 0

Original Oil In Place: 210.867 MMSTB

Start of Production: 01/01/2001 date d/m/y

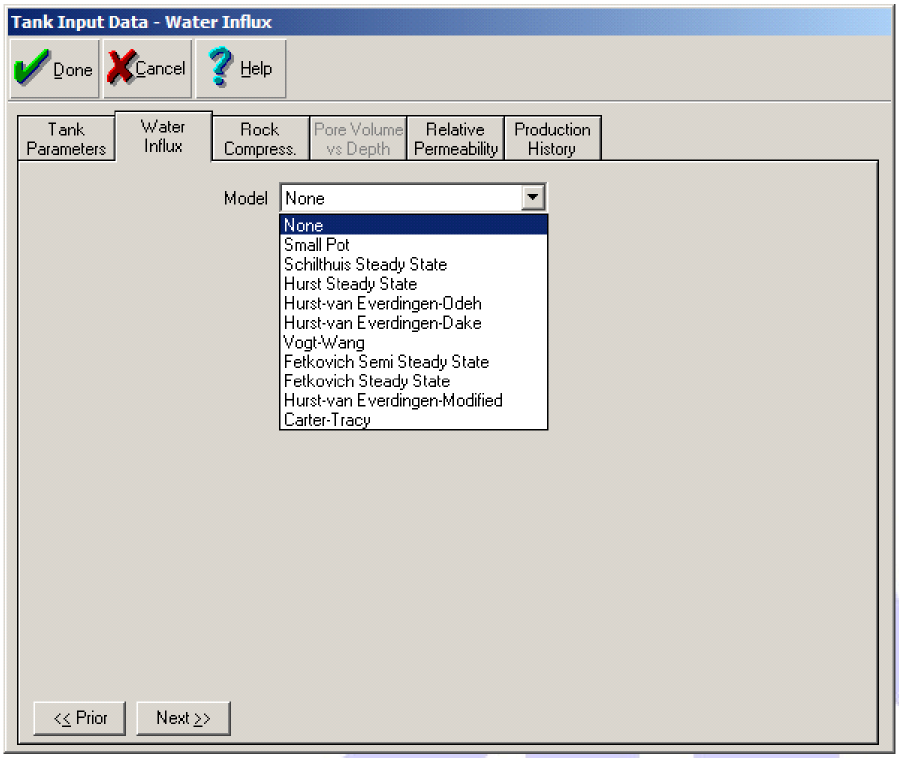
☐ Monitor Contacts

☐ Gas Coning

☐ Water Coning

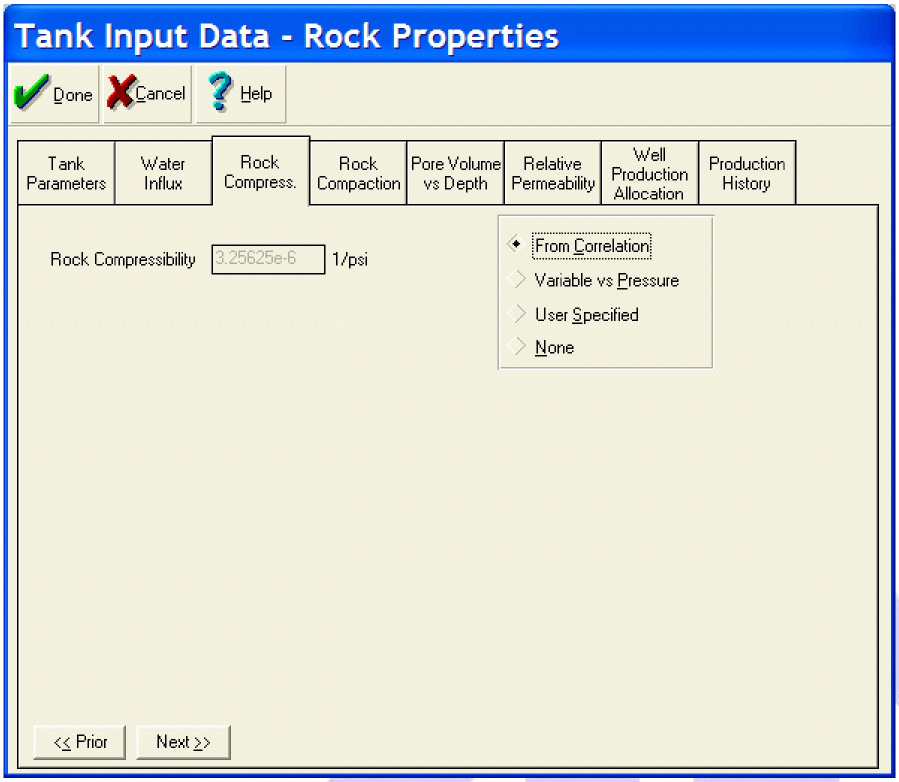
The OOIP entered in this screen is only an estimate, obtained from geology for example.

The next step is defining the aquifer support:


Tank Input Data - Water Influx
Done
Cancel
Help
Tank Parameters
Water Influx
Rock Compress.
Pore Volume vs Depth
Relative Permeability
Production History
Model
None
None
Small Pot
Schilthuis Steady State
Hurst Steady State
Hurst-van Everdingen-Odeh
Hurst-van Everdingen-Dake
Vogt-Wang
Fetkovich Semi Steady State
Fetkovich Steady State
Hurst-van Everdingen-Modified
Carter-Tracy
<< Prior
Next >>

As there is yet no evidence to suggest the presence of an aquifer, this will be left to "None" for the time being.

The rock compressibility options can be specified next:

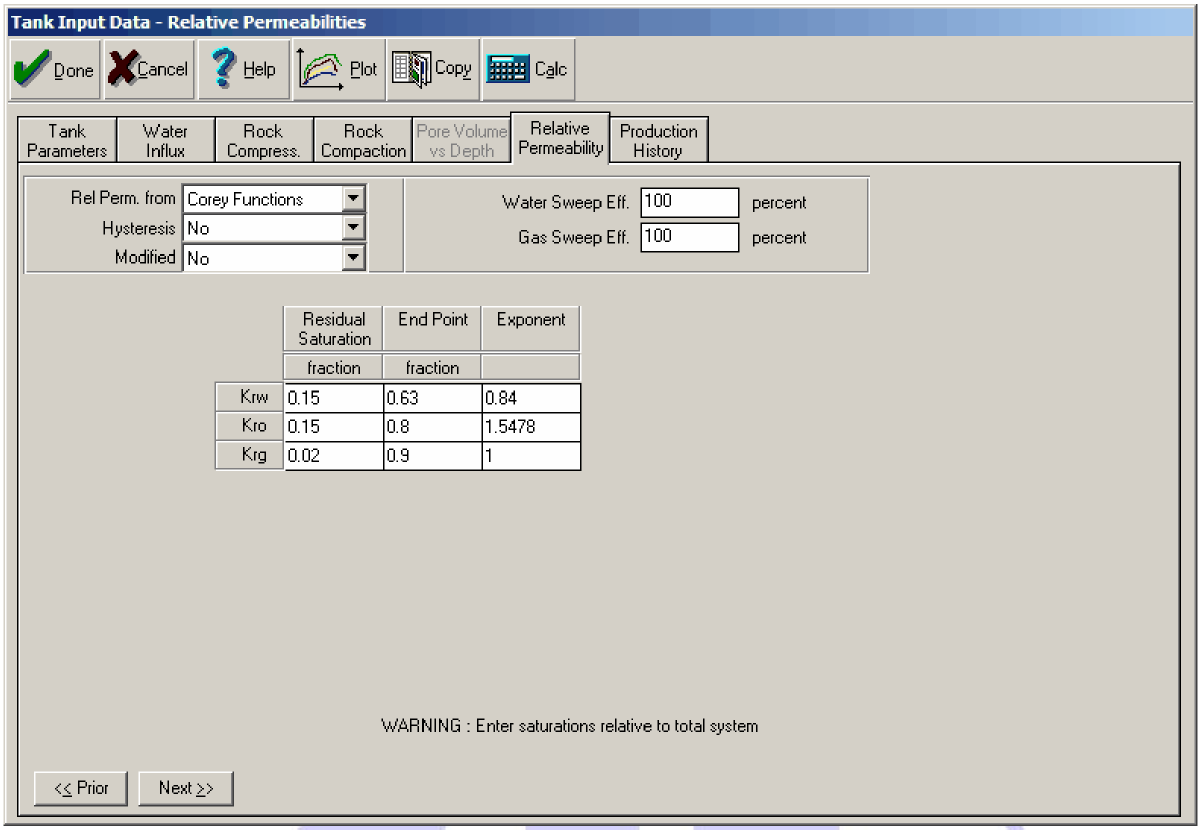


Tank Input Data - Rock Properties
Done
Cancel
Help
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Well Production Allocation
Production History
<< Prior
Next >>

Rock Compressibility 3.25625e-6 1/psi

● From Correlation
○ Variable vs Pressure
○ User Specified
○ None

As soon as the compressibility is entered, the rel perm information can be specified:


Tank Input Data - Relative Permeabilities
Done
Cancel
Help
Plot
Copy
Calc
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
<< Prior
Next >>

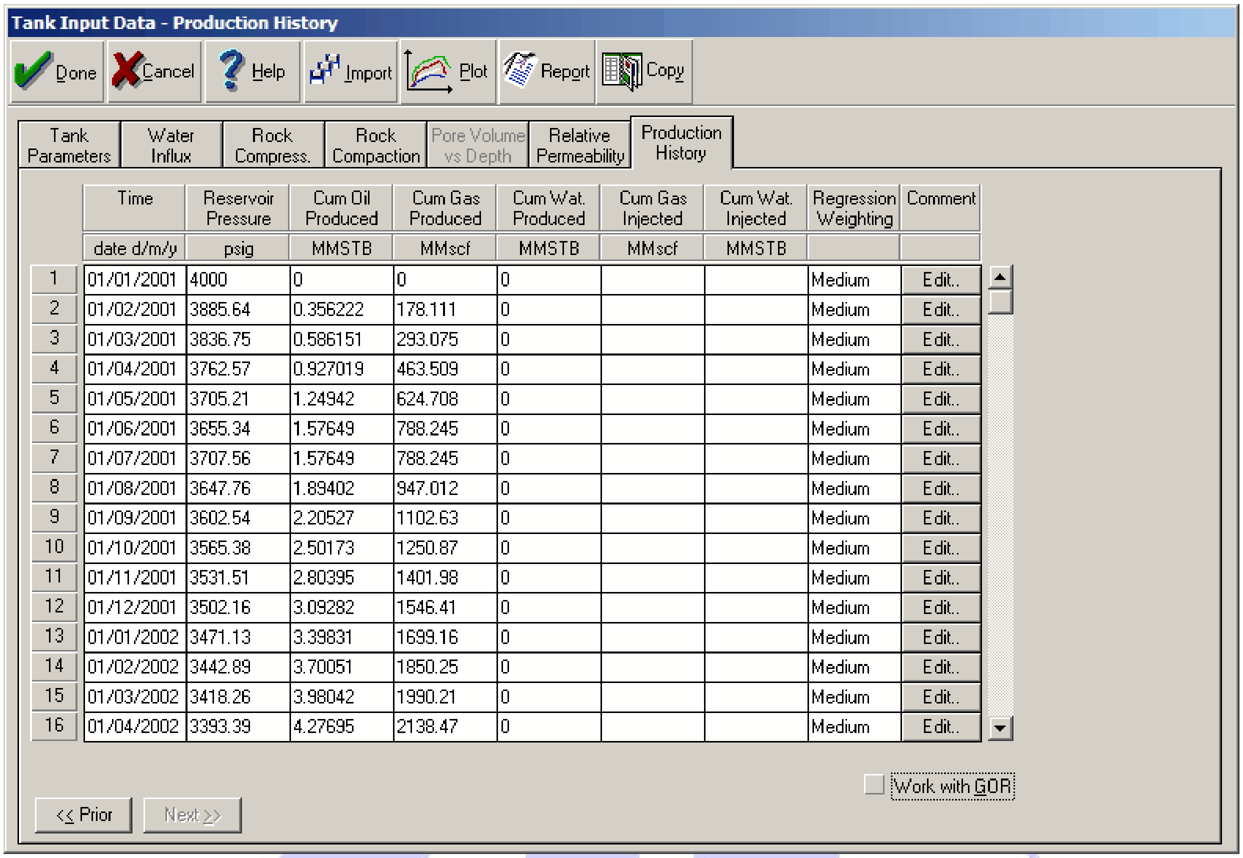
Rel Perm. from: Corey Functions
Hysteresis: No
Modified: No

Water Sweep Eff.: 100 percent
Gas Sweep Eff.: 100 percent

	Residual Saturation	End Point	Exponent
	fraction	fraction	
Krw	0.15	0.63	0.84
Kro	0.15	0.8	1.5478
Krg	0.02	0.9	1

WARNING : Enter saturations relative to total system

The last data that we have to supply is the production history of the reservoir as shown in the following screen. Note that this can be copied from the Excel file OILRES1.XLS.


Tank Input Data - Production History
Done
Cancel
Help
Import
Plot
Report
Copy
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
☐ Work with GOR
<< Prior
Next >>

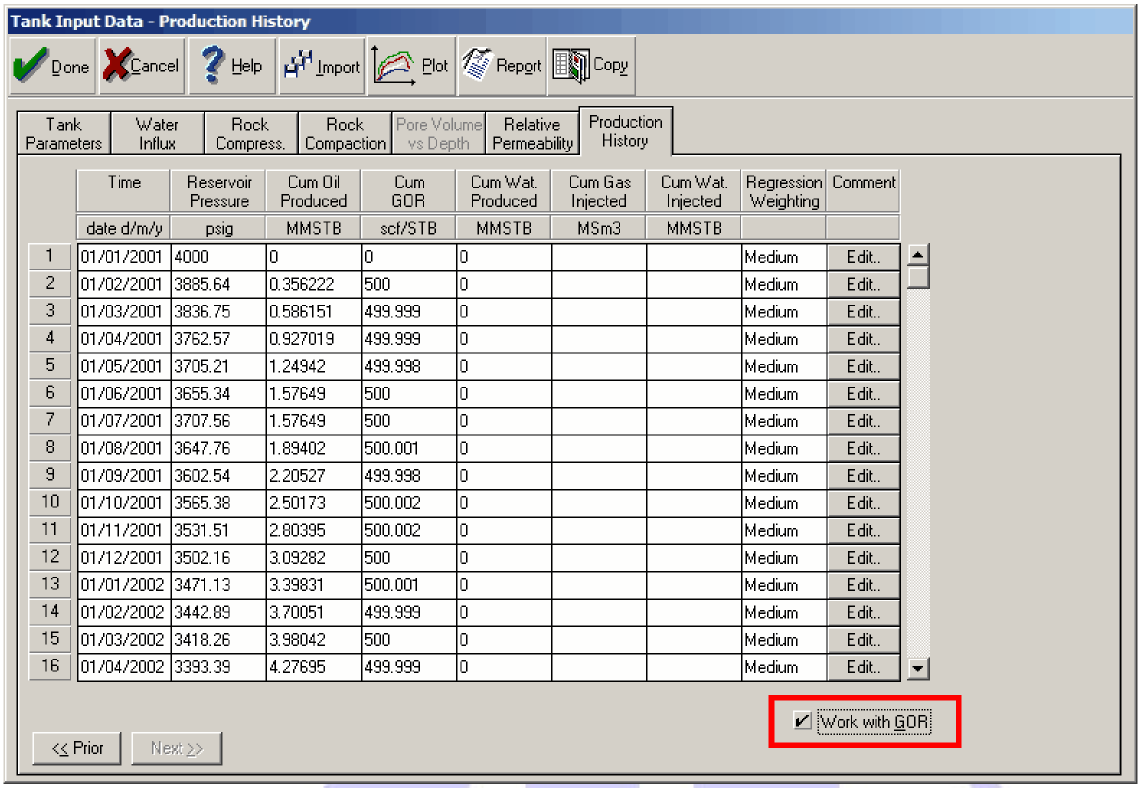
	Time	Reservoir Pressure	Cum Oil Produced	Cum Gas Produced	Cum Wat. Produced	Cum Gas Injected	Cum Wat. Injected	Regression Weighting	Comment
	date d/m/y	psig	MMSTB	MMscf	MMSTB	MMscf	MMSTB		
1	01/01/2001	4000	0	0	0			Medium	Edit..
2	01/02/2001	3885.64	0.356222	178.111	0			Medium	Edit..
3	01/03/2001	3836.75	0.586151	293.075	0			Medium	Edit..
4	01/04/2001	3762.57	0.927019	463.509	0			Medium	Edit..
5	01/05/2001	3705.21	1.24942	624.708	0			Medium	Edit..
6	01/06/2001	3655.34	1.57649	788.245	0			Medium	Edit..
7	01/07/2001	3707.56	1.57649	788.245	0			Medium	Edit..
8	01/08/2001	3647.76	1.89402	947.012	0			Medium	Edit..
9	01/09/2001	3602.54	2.20527	1102.63	0			Medium	Edit..
10	01/10/2001	3565.38	2.50173	1250.87	0			Medium	Edit..
11	01/11/2001	3531.51	2.80395	1401.98	0			Medium	Edit..
12	01/12/2001	3502.16	3.09282	1546.41	0			Medium	Edit..
13	01/01/2002	3471.13	3.39831	1699.16	0			Medium	Edit..
14	01/02/2002	3442.89	3.70051	1850.25	0			Medium	Edit..
15	01/03/2002	3418.26	3.98042	1990.21	0			Medium	Edit..
16	01/04/2002	3393.39	4.27695	2138.47	0			Medium	Edit..

This finishes our setting up of basic tank model. It is advisable to save the file at this point. Next step would be to history match the model, in terms of identifying and quantifying its various drive mechanisms and determining the OOIP and aquifer support.

Show them how to paste in a table

3.1.3 Matching to Production History data in MBAL

The first thing to do is to see whether our production history data is consistent with our PVT data. In the PVT section we indicated that the bubble point was 2200 psig and the solution GOR was 500 Scf/STB. If we go to the production history screen in the tank input data, we can click on the option **Work with GOR** at the bottom of the dialogue and the gas rates are converted into producing GOR values.

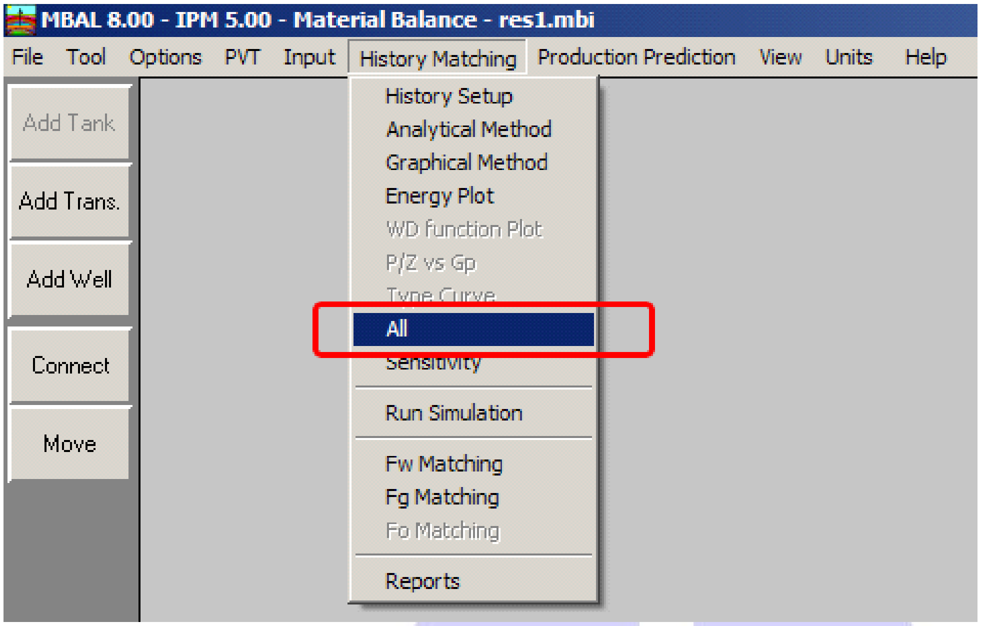

Tank Input Data - Production History
Done
Cancel
Help
Import
Plot
Report
Copy
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
<< Prior
Next >>

	Time	Reservoir Pressure	Cum Oil Produced	Cum GOR	Cum Wat. Produced	Cum Gas Injected	Cum Wat. Injected	Regression Weighting	Comment
	date d/m/y	psig	MMSTB	scf/STB	MMSTB	MSm3	MMSTB		
1	01/01/2001	4000	0	0	0			Medium	Edit..
2	01/02/2001	3885.64	0.356222	500	0			Medium	Edit..
3	01/03/2001	3836.75	0.586151	499.999	0			Medium	Edit..
4	01/04/2001	3762.57	0.927019	499.999	0			Medium	Edit..
5	01/05/2001	3705.21	1.24942	499.998	0			Medium	Edit..
6	01/06/2001	3655.34	1.57649	500	0			Medium	Edit..
7	01/07/2001	3707.56	1.57649	500	0			Medium	Edit..
8	01/08/2001	3647.76	1.89402	500.001	0			Medium	Edit..
9	01/09/2001	3602.54	2.20527	499.998	0			Medium	Edit..
10	01/10/2001	3565.38	2.50173	500.002	0			Medium	Edit..
11	01/11/2001	3531.51	2.80395	500.002	0			Medium	Edit..
12	01/12/2001	3502.16	3.09282	500	0			Medium	Edit..
13	01/01/2002	3471.13	3.39831	500.001	0			Medium	Edit..
14	01/02/2002	3442.89	3.70051	499.999	0			Medium	Edit..
15	01/03/2002	3418.26	3.98042	500	0			Medium	Edit..
16	01/04/2002	3393.39	4.27695	499.999	0			Medium	Edit..

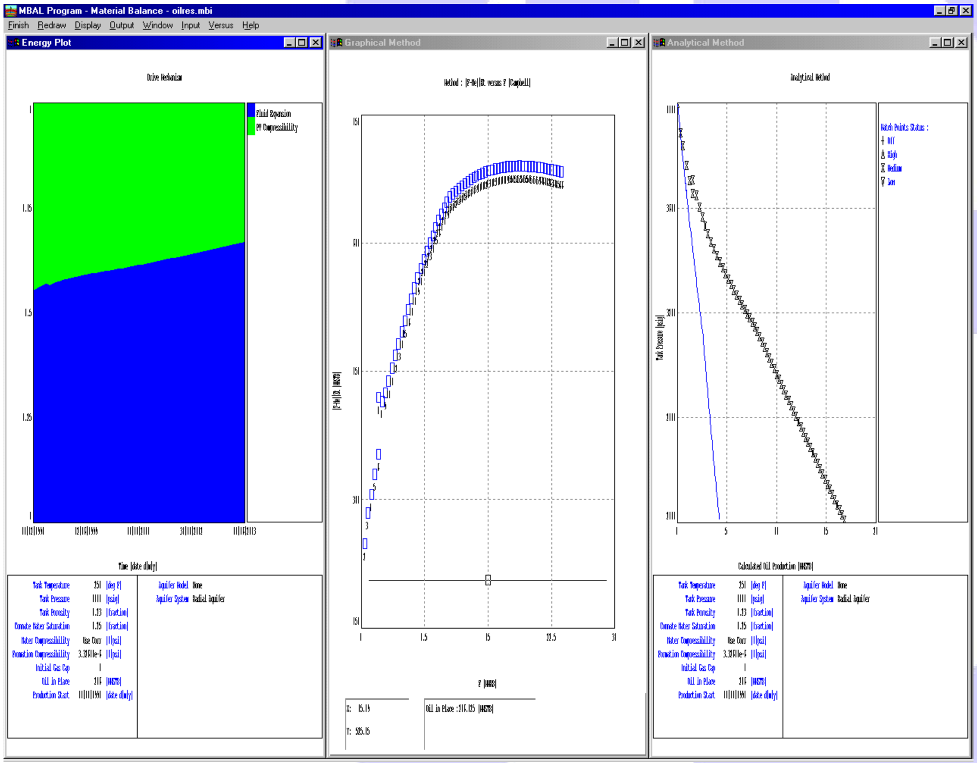
☑ Work with GOR

From the production history table, it can be seen that the GOR remains at a constant value indicating that the reservoir pressure remains above 2200 psig. Since the pressure is always above the bubble point, there should be no free gas and hence the producing GOR should be equal to the solution GOR. Thus the data is consistent with the PVT. If this was not the case, then there would be an inconsistency between PVT and production data. The source of this inconsistency would need to be identified before progressing with the history match.

Having determined that there are no inconsistencies in the data, the history matching process can begin:


MBAL 8.00 - IPM 5.00 - Material Balance - res1.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Add Tank
Add Trans.
Add Well
Connect
Move
History Setup
Analytical Method
Graphical Method
Energy Plot
WD Function Plot
P/Z vs Gp
Type Curve
All
Sensitivity
Run Simulation
Fw Matching
Fg Matching
Fo Matching
Reports

This will prompt the plots used for history matching as shown below:

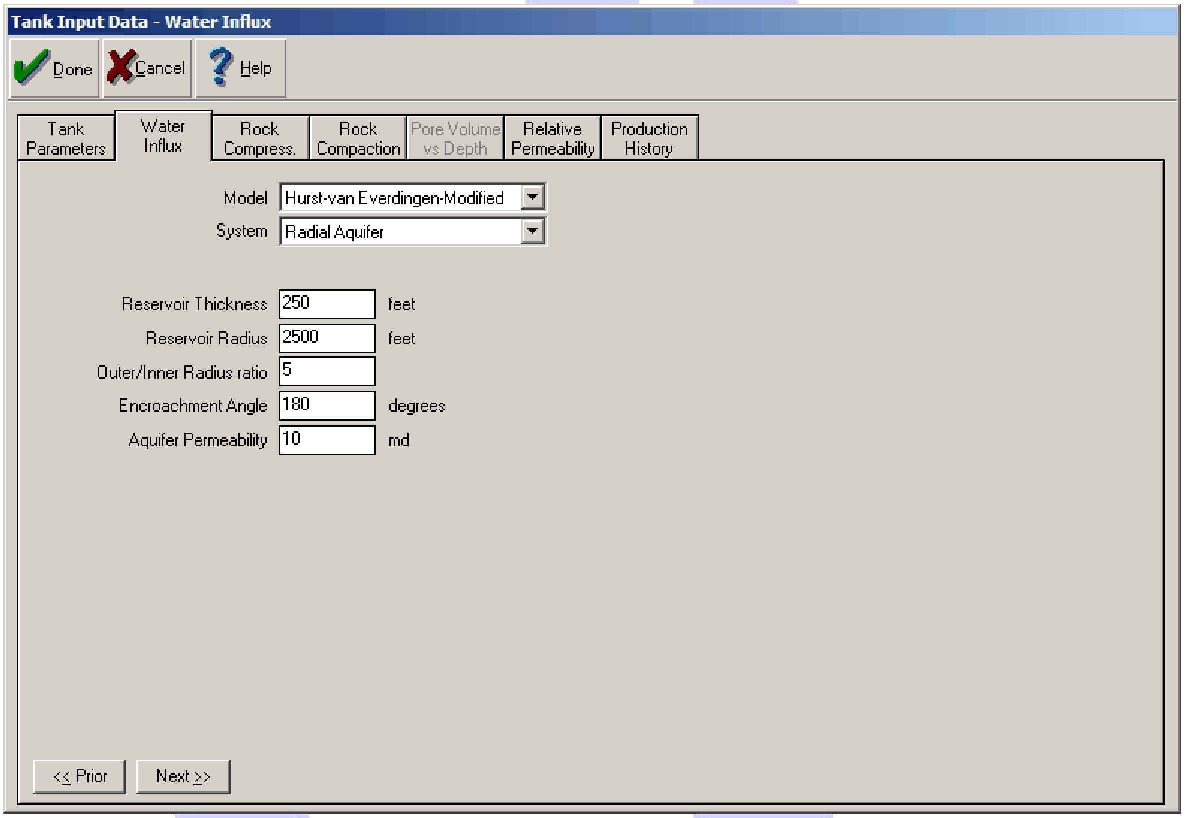

MBAL Program - Material Balance - oilres.mbi
Finish
Redraw
Display
Output
Window
Input
Versus
Help
Energy Plot
Graphical Method
Analytical Method

Three plots are available. The energy plot, showing the relative importance of each drive mechanism currently in the model, the Graphical method where the diagnostics in terms of drives can be done, and the Analytical method plot that shows the reservoir pressure Vs Cum

Production from the historical data and the model.

Add a link to where there is greater detail concerning the plots.

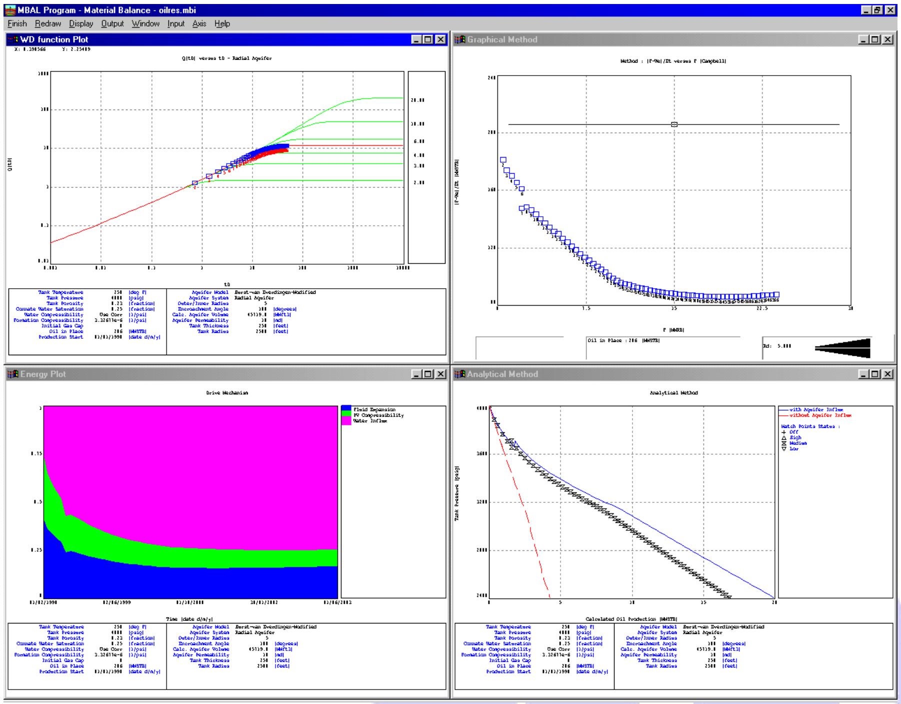
Note that in the graphical methods the plot shown in the screen above is the Campbell plot. This plots the STOIIP along the Y-axis which never changes. However, the Campbell plot does show variation which indicates that an unaccounted energy source is contributing to the historical production.
Based on the response of the Campbell plot, the presence of an aquifer is very likely (source of energy). Therefore an aquifer model can be selected in the tank data section:


Tank Input Data - Water Influx
Done
Cancel
Help
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
<< Prior
Next >>

Model: Hurst-van Everdingen-Modified
System: Radial Aquifer

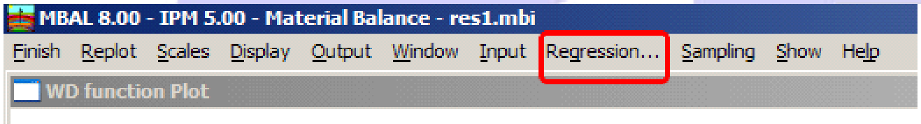
Reservoir Thickness: 250 feet
Reservoir Radius: 2500 feet
Outer/Inner Radius ratio: 5
Encroachment Angle: 180 degrees
Aquifer Permeability: 10 md

Going back to History Matching/All, the W_D function plot (for the aquifer) will now be shown as well as the three plots seen originally:

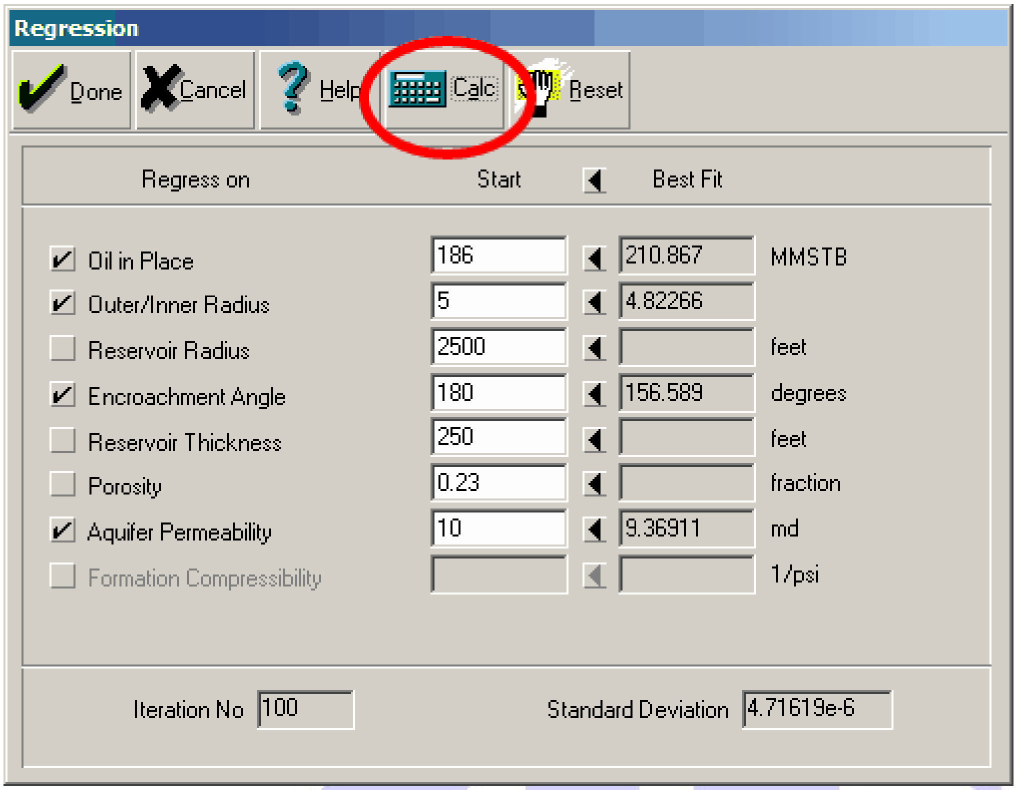

MBAL Program - Material Balance - oilres.mbi
Finish Redraw Display Output Window Input Axis Help
WD function Plot
Graphical Method
Energy Plot
Drive Mechanism
Analytical Method

Look at the analytical method plot, it can be seen that with the current aquifer model, the model is predicting production rates higher than those actually observed. The aquifer parameters along with the OOIP can now be changed so that the Campbell plot will become a straight horizontal line and the model matched the measured data in the analytical method plot.

To activate the regression analysis button, the analytical plot has to be selected (by clicking once on the title bar of this plot for example) and in the menu bar of the above screen select the **Regression** option that will now appear:


MBAL 8.00 - IPM 5.00 - Material Balance - res1.mbi
Finish
Replot
Scales
Display
Output
Window
Input
Regression...
Sampling
Show
Help
WD function Plot

Selecting this option will prompt the 'Regression' screen that will enable the selection of parameters to regress on. This eliminates the manual change of parameters to get a match between model and data which was done in the classical material balance calculations.



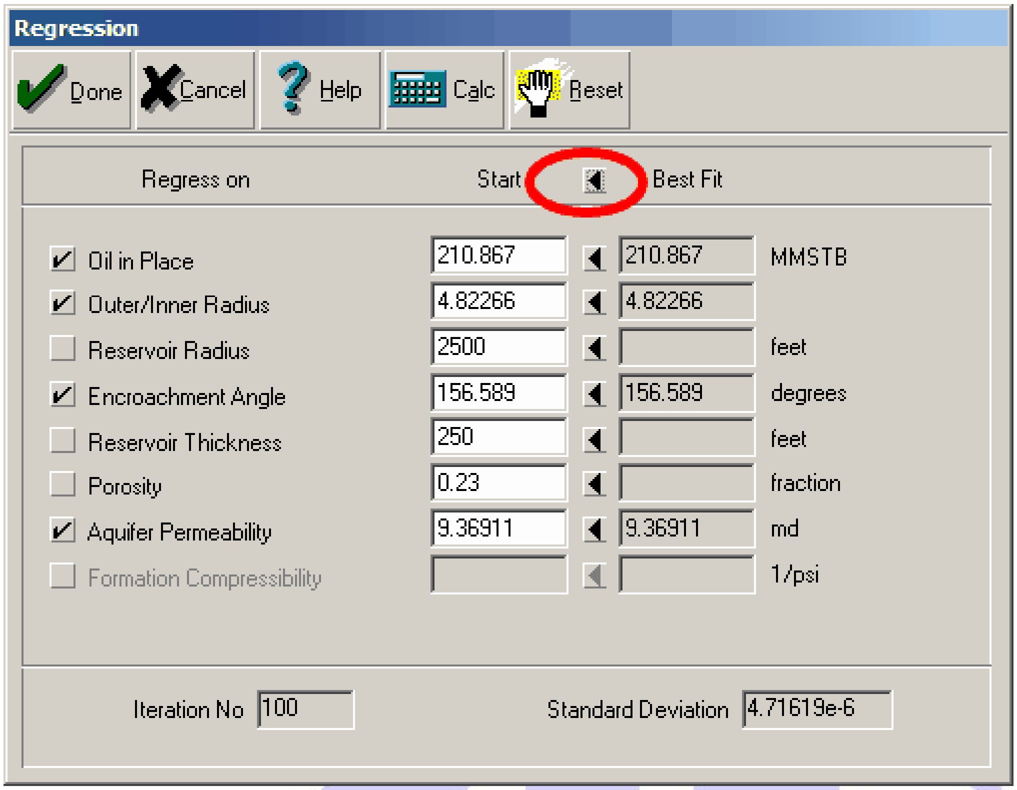
	Start		Best Fit	
☑ Oil in Place	186	◀	210.867	MMSTB
☑ Outer/Inner Radius	5	◀	4.82266	
☐ Reservoir Radius	2500	◀		feet
☑ Encroachment Angle	180	◀	156.589	degrees
☐ Reservoir Thickness	250	◀		feet
☐ Porosity	0.23	◀		fraction
☑ Aquifer Permeability	10	◀	9.36911	md
☐ Formation Compressibility		◀		1/psi

Iteration No 100

Standard Deviation 4.71619e-6

The parameters to select for regression will be the ones least trusted or the ones for which values were assumed rather than measured. In this case, the STOIIP and the least trusted aquifer parameters were selected.

At the end of regression the values for which the best match is achieved are displayed. If they are accepted, then the “Best Fit” button can be selected in order to transfer these values into the model:

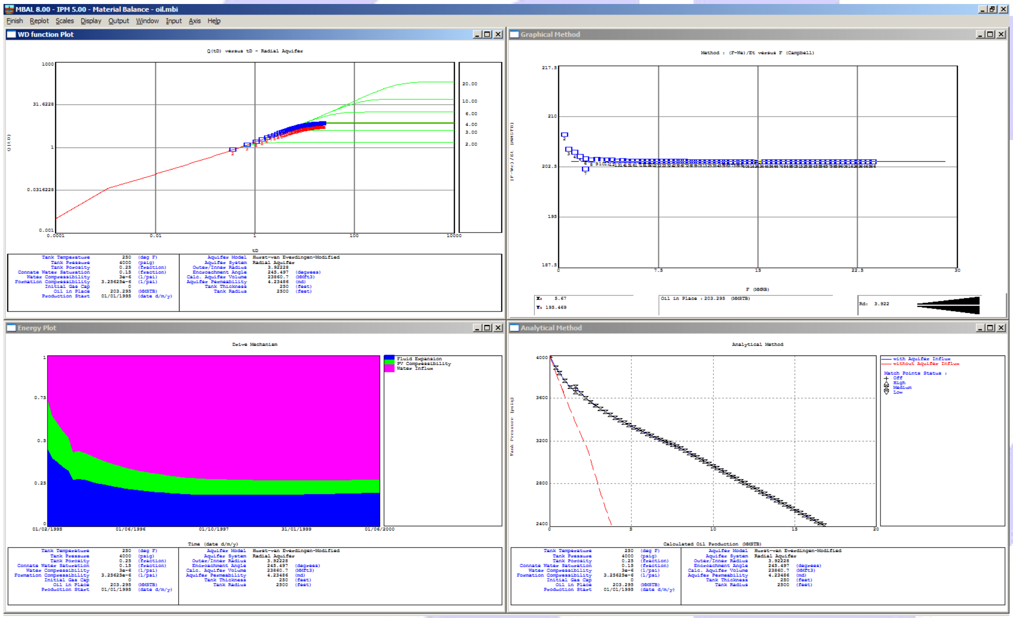

Regression
Done
Cancel
Help
Calc
Reset

Regress on	Start	Best Fit	
☑ Oil in Place	210.867	210.867	MMSTB
☑ Outer/Inner Radius	4.82266	4.82266	
☐ Reservoir Radius	2500		feet
☑ Encroachment Angle	156.589	156.589	degrees
☐ Reservoir Thickness	250		feet
☐ Porosity	0.23		fraction
☑ Aquifer Permeability	9.36911	9.36911	md
☐ Formation Compressibility			1/psi

Iteration No 100

Standard Deviation 4.71619e-6

After transferring the data if we click on done we get the following plots:


MBAL 8.00 - IPM 5.00 - Material Balance - oil.mbi
Finish Replot Scales Display Output Window Input Axis Help
WD function Plot
Graphical Method
Energy Plot
Analytical Method

The model obtained at this stage in terms of STOIIP and various drive mechanisms satisfies all the methods and is therefore acceptable.

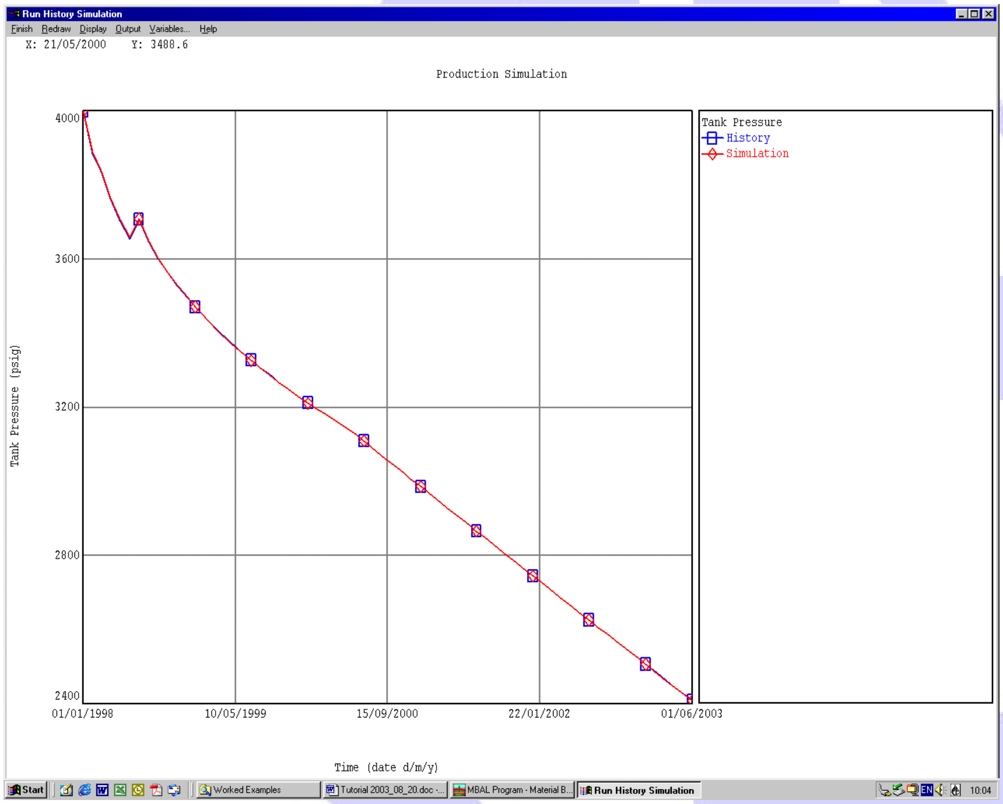
This file can now be saved as **Oilres.mbi**.

3.1.3.1 Using Simulation Option to Quality Check the History Matched Model

At this stage it should be noted that the regression analysis carried out in the analytical plot was to apply material balance to the system to back-calculate the pressures and STOIIP which resulted in the measured historical data.

The simulation option will perform the opposite calculation. With the model now history matched, the phase rates from the history are kept and the pressure is calculated from the material balance equations. If the model has been properly history matched, there should be no discrepancy between reservoir pressures predicted from simulation and historical, measured reservoir pressures.

From the main menu the option **History Matching | Run simulation | Calculate** can be selected. At the end of calculation, the 'Plot' option can be selected and the following plot will appear:


Run History Simulation
Finish Redraw Display Output Variables... Help
X: 21/05/2000 Y: 3488.6
Production Simulation
Tank Pressure (psig)
4000
3600
3200
2800
2400
01/01/1998
10/05/1999
15/09/2000
22/01/2002
01/06/2003
Time (date d/m/y)
Tank Pressure
History
Simulation
Start
Worked Examples
Tutorial 2003_08_20.doc -...
MBAL Program - Material B...
Run History Simulation
EN
10:04

This plot has the pressure with time plotted both from simulation and production history data. In this case both are identical and thus the match attained is good.

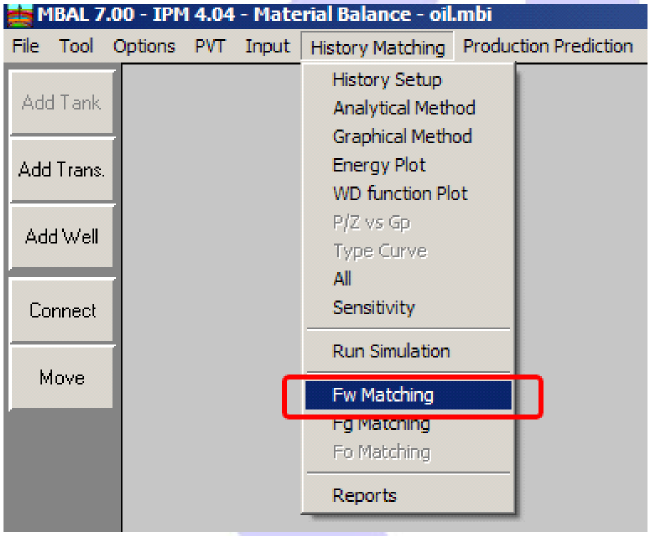
Note: The model is not ready at this stage to go ahead with predictions and study various development alternatives. Fractional flow matching should be done that will create pseudo relative permeability curves based on history. This is the best way to ensure that WC and GOR evolution in the future will be predicted correctly.

3.1.4 Forecasting

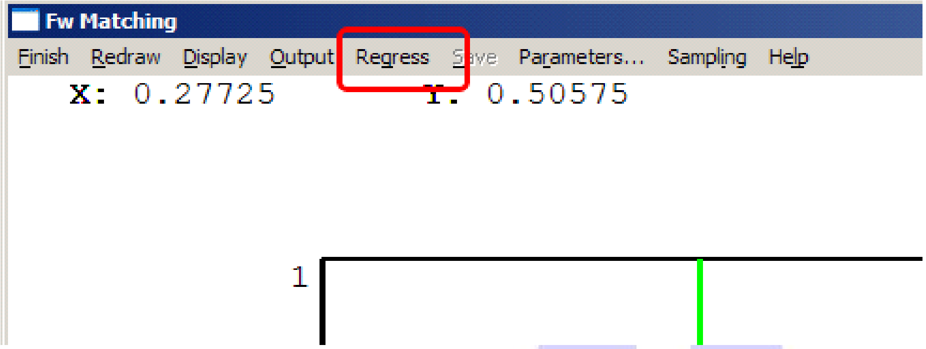
In performing forecasts with a history matched model, the amount of water and gas production (water cut and GOR) needs to be predicted accurately. Traditionally, there was no way to do this as material balance does not account for geology.
In **MBAL** the use of pseudo rel perms is employed in predicting the water cut and GOR that would flow in the well along with the oil, which in this case is the main phase. These rel perm sets provide the basis on which fractional flow curves are built, following the procedure outlined below.

3.1.4.1 Rel Perm Matching

The creation of the fractional flow curves is carried out under the 'History Matching' heading:

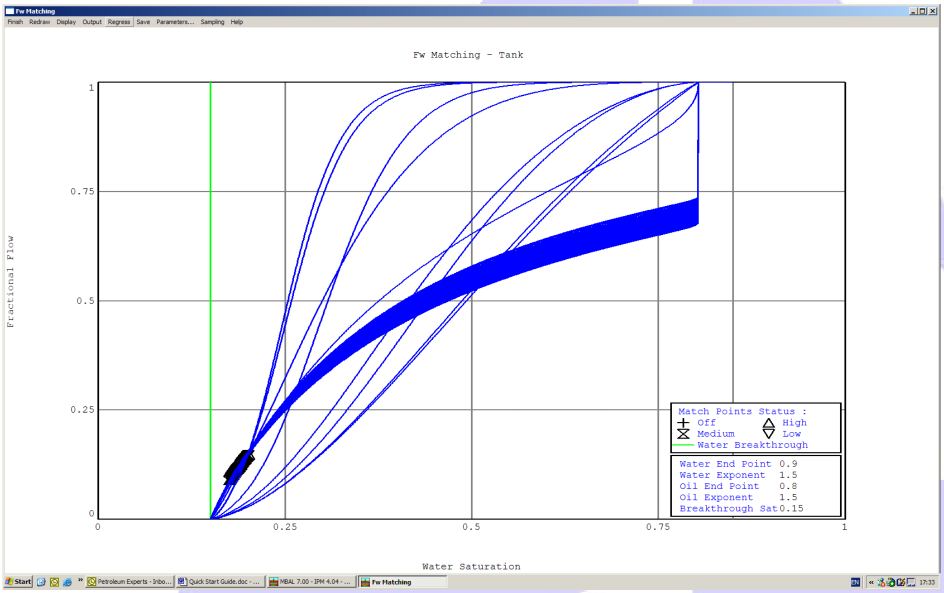

MBAL 7.00 - IPM 4.04 - Material Balance - oil.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
Add Tank
Add Trans.
Add Well
Connect
Move
History Setup
Analytical Method
Graphical Method
Energy Plot
WD function Plot
P/Z vs Gp
Type Curve
All
Sensitivity
Run Simulation
Fw Matching
Fg Matching
Fo Matching
Reports

The matching of the fractional flow curves can be carried out for water and gas in the system.
By selecting the “Regress” button on the menu bar of this screen, the program will regress on the available historical data in order to fit the fractional flow curve to them. This will in turn create a set of rel perm curves that will then be used to predict the fractional flow (in this case) of water when saturation in the tank increases.


Fw Matching
Finish
Redraw
Display
Output
Regress
Save
Parameters...
Sampling
Help
1

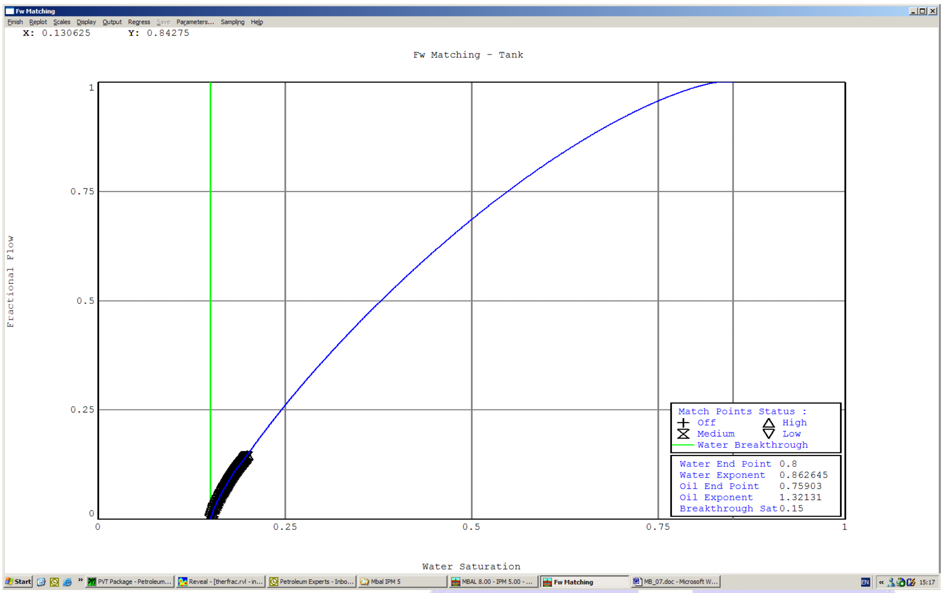
X: 0.27725 Y: 0.50575

While the regression progresses, the curves that the program is trying to match will be shown on the screen:


Fw Matching
Finish
Redraw
Display
Output
Regress
Save
Parameters...
Sampling
Help
Fw Matching - Tank
Fractional Flow
1
0.75
0.5
0.25
0
0
0.25
0.5
0.75
1
Water Saturation
Match Points Status :
Off
High
Medium
Low
Water Breakthrough

Water End Point 0.9
Water Exponent 1.5
Oil End Point 0.8
Oil Exponent 1.5
Breakthrough Sat 0.15

The end result will be a curve fitting the data:

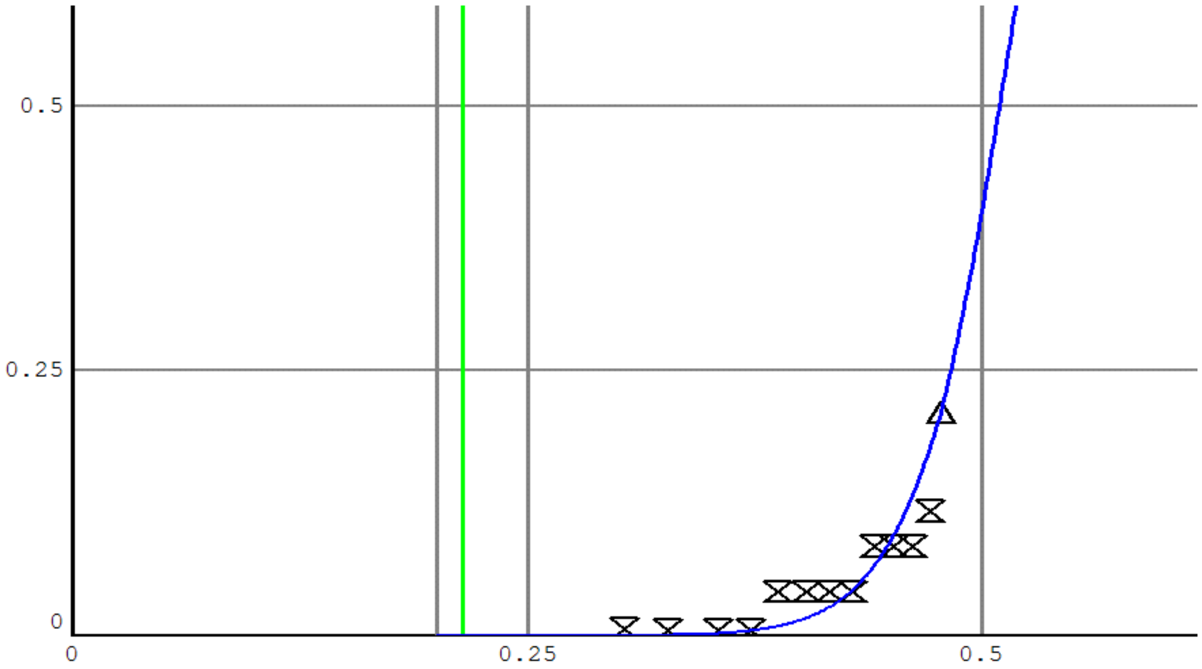

Fw Matching
Finish Replot Scales Display Output Regress Save Parameters... Sampling Help
X: 0.130625 Y: 0.84275
Fw Matching - Tank
Fractional Flow
1
0.75
0.5
0.25
0
0
0.25
0.5
0.75
1
Water Saturation
Match Points Status :
Off
High
Medium
Low
Water Breakthrough

Water End Point 0.8
Water Exponent 0.862645
Oil End Point 0.75903
Oil Exponent 1.32131
Breakthrough Sat 0.15

The same can be done for the gas fractional flow. In this case however, this is not possible as no free gas is available so the rel perms input in the reservoir data screen will be accepted for the forecast.

3.1.4.2 Confirming the validity of the rel perms

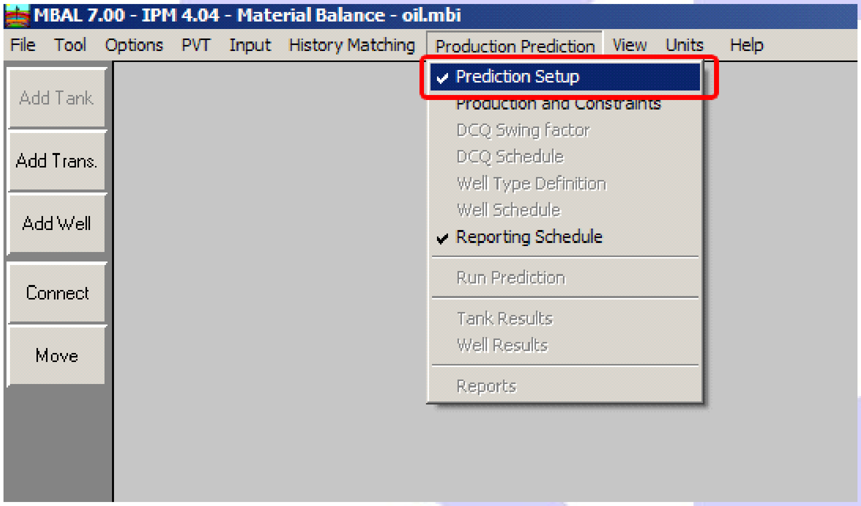
In cases where the match between the fractional flow curve and the historical points is good, the model is expected to reproduce the historical water cuts well. However, in reality, this match is not always perfect because of errors in the data and scatter in the points. An example is shown below:



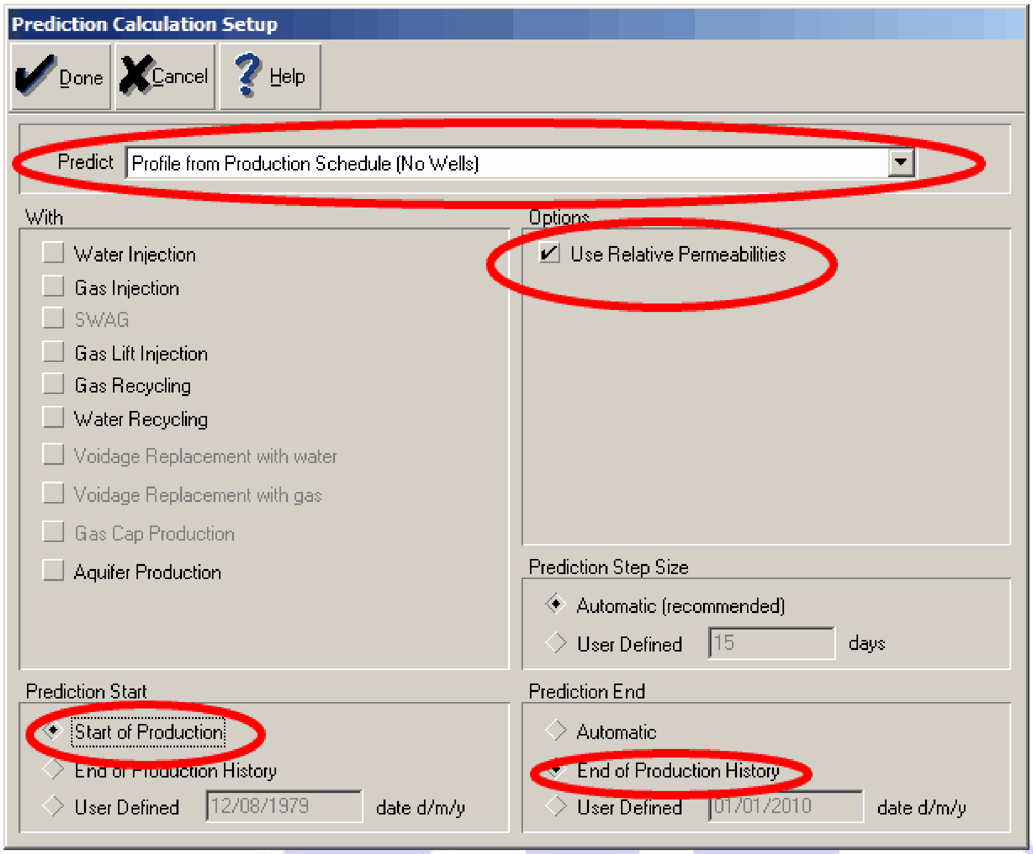
In order to quantify exactly how much difference there is in terms of actual water cut in the history and the match of the model, then a “Prediction of History” needs to be done, where the historical production of oil will be fixed (as measured) but not the production of water or gas. These will be calculated based on the fractional flow curves and then compared to the historical production.

In doing this forecast, this is the procedure to be followed:

Step 1: Under production prediction, the prediction setup option can be selected:


MBAL 7.00 - IPM 4.04 - Material Balance - oil.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Add Tank
Add Trans.
Add Well
Connect
Move
✓ Prediction Setup
Production and Constraints
DCQ Swing Factor
DCQ Schedule
Well Type Definition
Well Schedule
✓ Reporting Schedule
Run Prediction
Tank Results
Well Results
Reports

Step 2: The following options need to be selected:



Prediction Calculation Setup

Predict: Profile from Production Schedule (No Wells)

With
☐ Water Injection
☐ Gas Injection
☐ SWAG
☐ Gas Lift Injection
☐ Gas Recycling
☐ Water Recycling
☐ Voidage Replacement with water
☐ Voidage Replacement with gas
☐ Gas Cap Production
☐ Aquifer Production

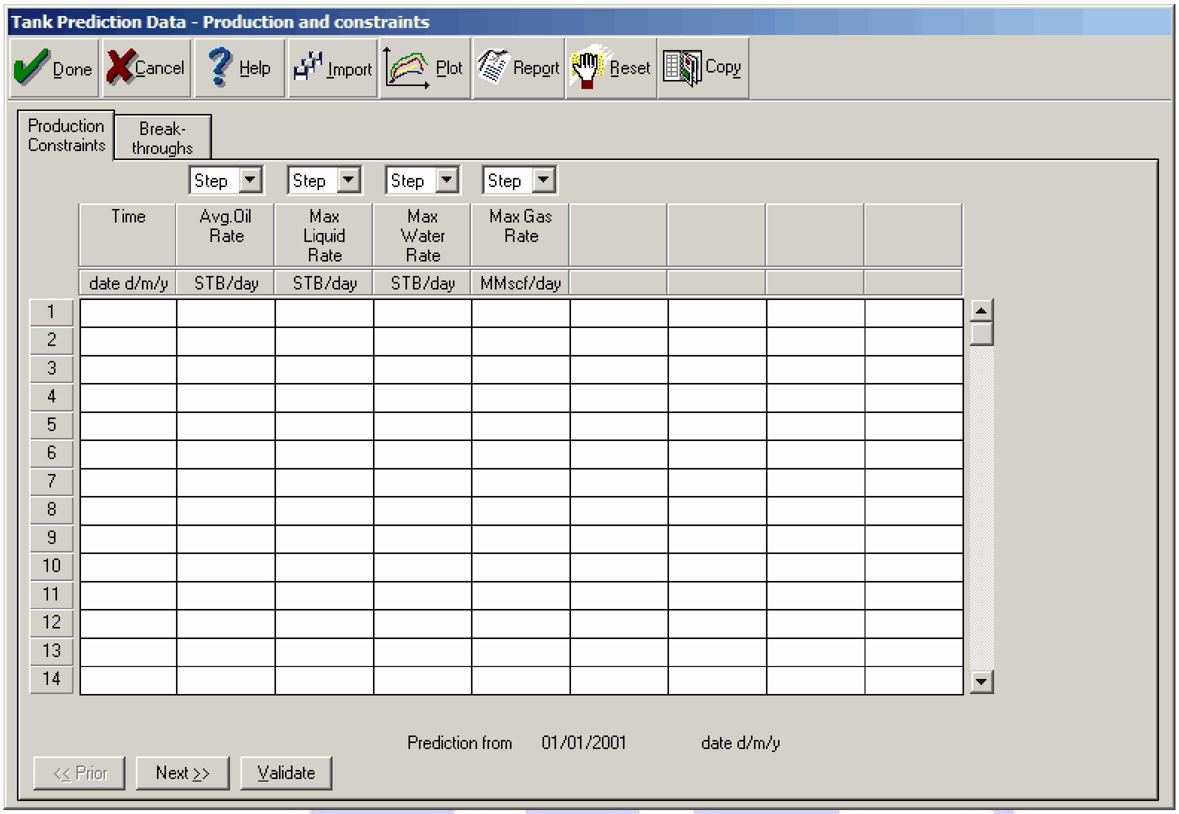
Options
☑ Use Relative Permeabilities

Prediction Step Size
● Automatic (recommended)
○ User Defined 15 days

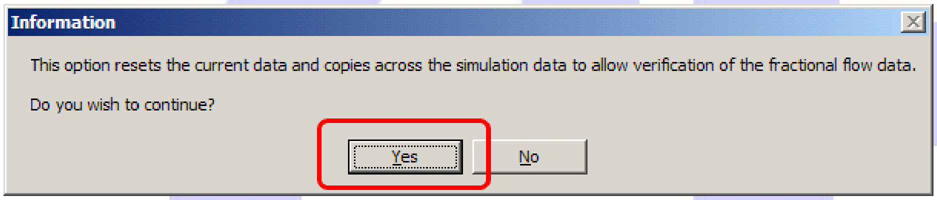
Prediction Start
● Start of Production
○ End of Production History
○ User Defined 12/08/1979 date d/m/y

Prediction End
○ Automatic
● End of Production History
○ User Defined 01/01/2010 date d/m/y

Step 3: Set the historical production volumes of oil to be extracted from the tank:


Tank Prediction Data - Production and constraints
Done
Cancel
Help
Import
Plot
Report
Reset
Copy
Production Constraints
Break-throughs
Step
Step
Step
Step
Time
Avg.Oil Rate
Max Liquid Rate
Max Water Rate
Max Gas Rate
date d/m/y
STB/day
STB/day
STB/day
MMscf/day
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Prediction from
01/01/2001
date d/m/y
<< Prior
Next >>
Validate

When the “Copy” button is selected, the program will prompt the following message:

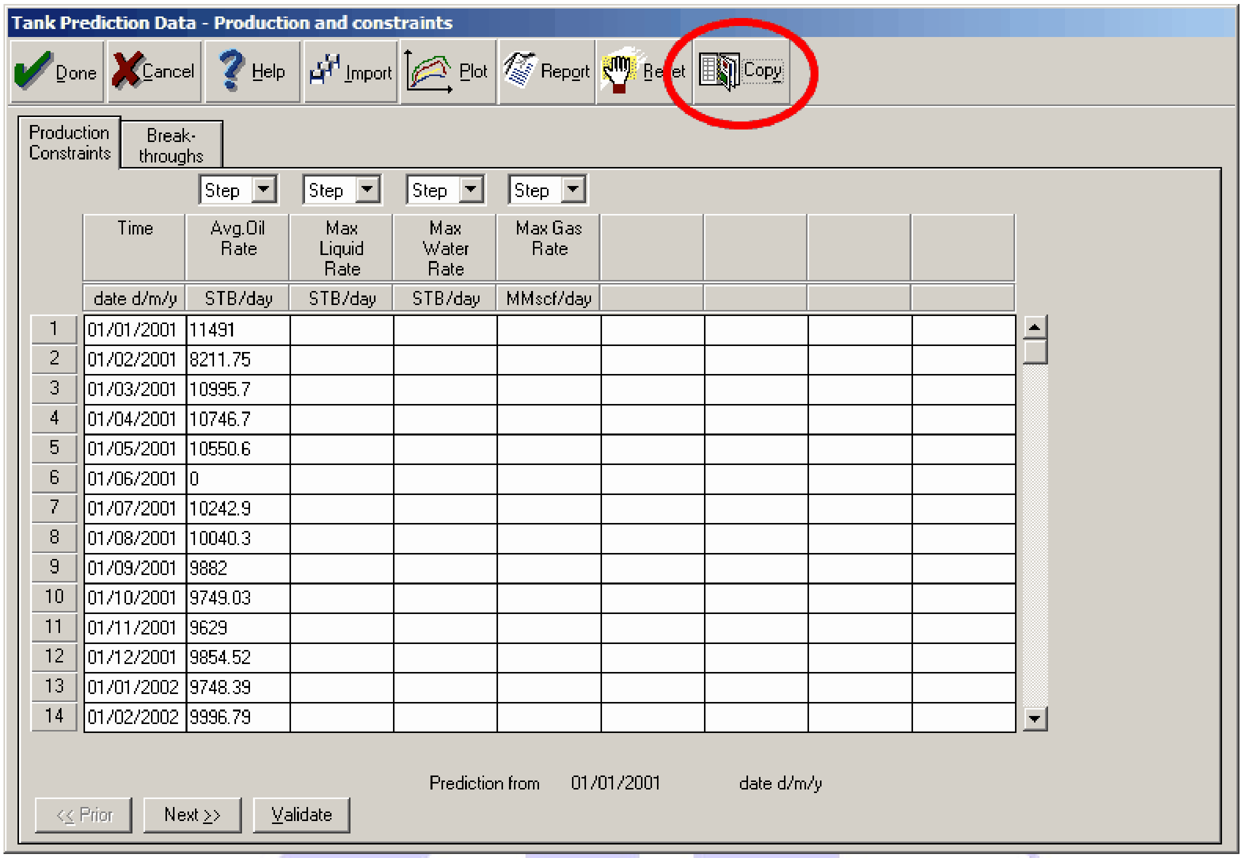

Information

This option resets the current data and copies across the simulation data to allow verification of the fractional flow data.

Do you wish to continue?

Yes
No

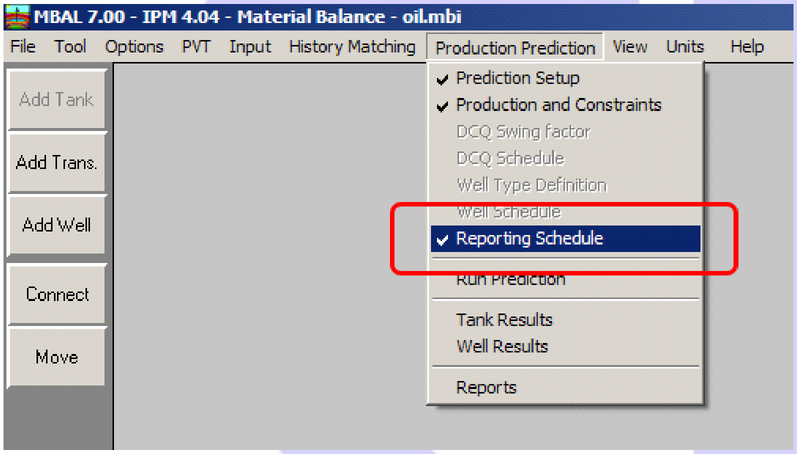
The historical rates will then be copied across:


Tank Prediction Data - Production and constraints
Done
Cancel
Help
Import
Plot
Report
Reset
Copy
Production Constraints
Break-throughs
Step
Step
Step
Step
<< Prior
Next >>
Validate

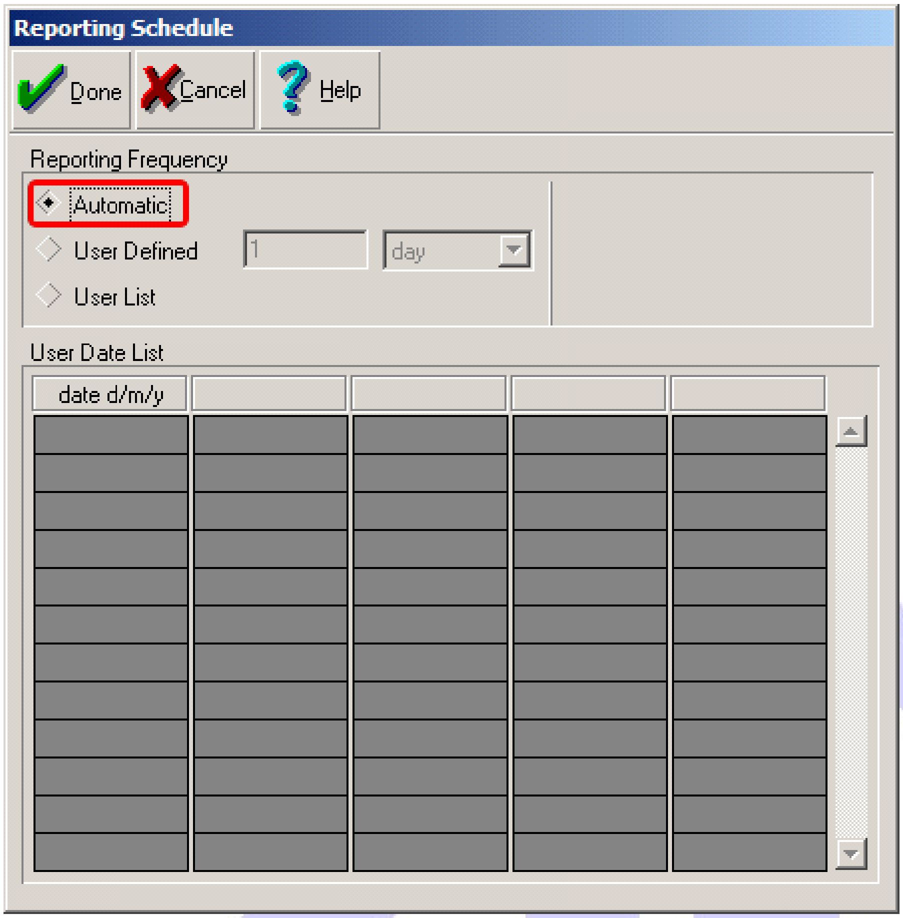
	Time	Avg.Oil Rate	Max Liquid Rate	Max Water Rate	Max Gas Rate				
	date d/m/y	STB/day	STB/day	STB/day	MMscf/day				
1	01/01/2001	11491							
2	01/02/2001	8211.75							
3	01/03/2001	10995.7							
4	01/04/2001	10746.7							
5	01/05/2001	10550.6							
6	01/06/2001	0							
7	01/07/2001	10242.9							
8	01/08/2001	10040.3							
9	01/09/2001	9882							
10	01/10/2001	9749.03							
11	01/11/2001	9629							
12	01/12/2001	9854.52							
13	01/01/2002	9748.39							
14	01/02/2002	9996.79							

Prediction from 01/01/2001 date d/m/y

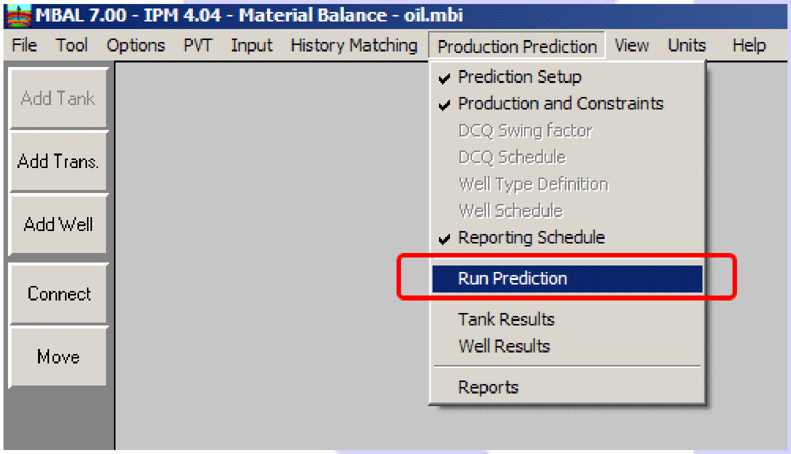
Step 4: Setting the reporting schedule:


MBAL 7.00 - IPM 4.04 - Material Balance - oil.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Add Tank
Add Trans.
Add Well
Connect
Move
✓ Prediction Setup
✓ Production and Constraints
DCQ Swing Factor
DCQ Schedule
Well Type Definition
Well Schedule
✓ Reporting Schedule
Run Prediction
Tank Results
Well Results
Reports

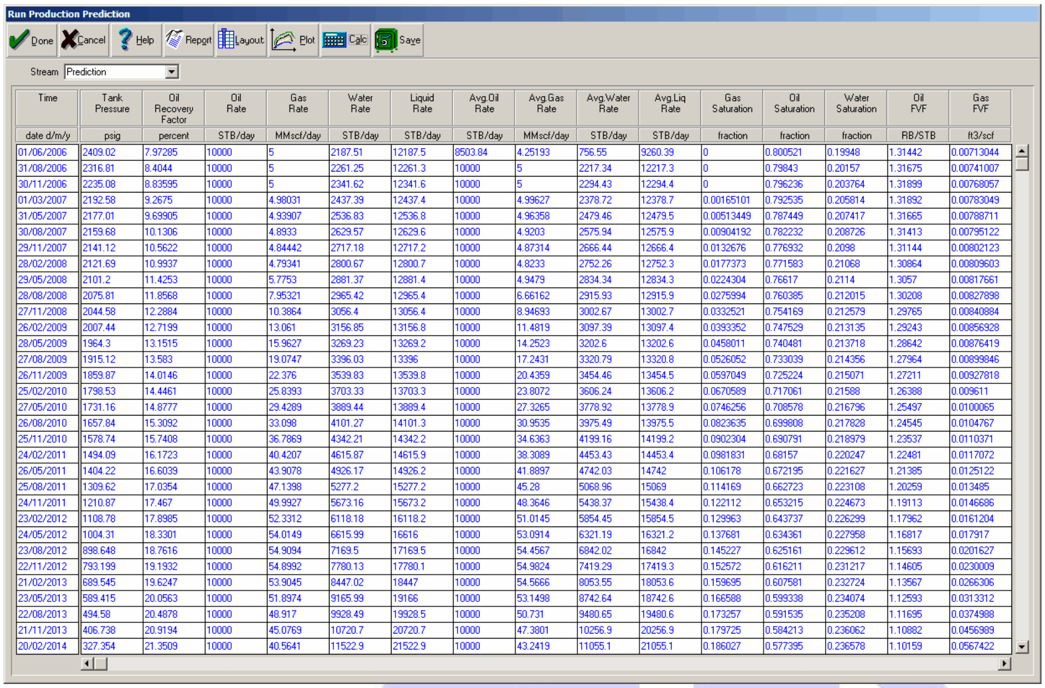
In the following screen, the schedule is set to automatic:


Reporting Schedule
Done
Cancel
Help
Reporting Frequency
Automatic
User Defined
1
day
User List
User Date List
date d/m/y

Step 5: Running the prediction:


MBAL 7.00 - IPM 4.04 - Material Balance - oil.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Add Tank
Add Trans.
Add Well
Connect
Move
Prediction Setup
Production and Constraints
DCQ Swing factor
DCQ Schedule
Well Type Definition
Well Schedule
Reporting Schedule
Run Prediction
Tank Results
Well Results
Reports

In the following screen, the “Calc” button will run the prediction:

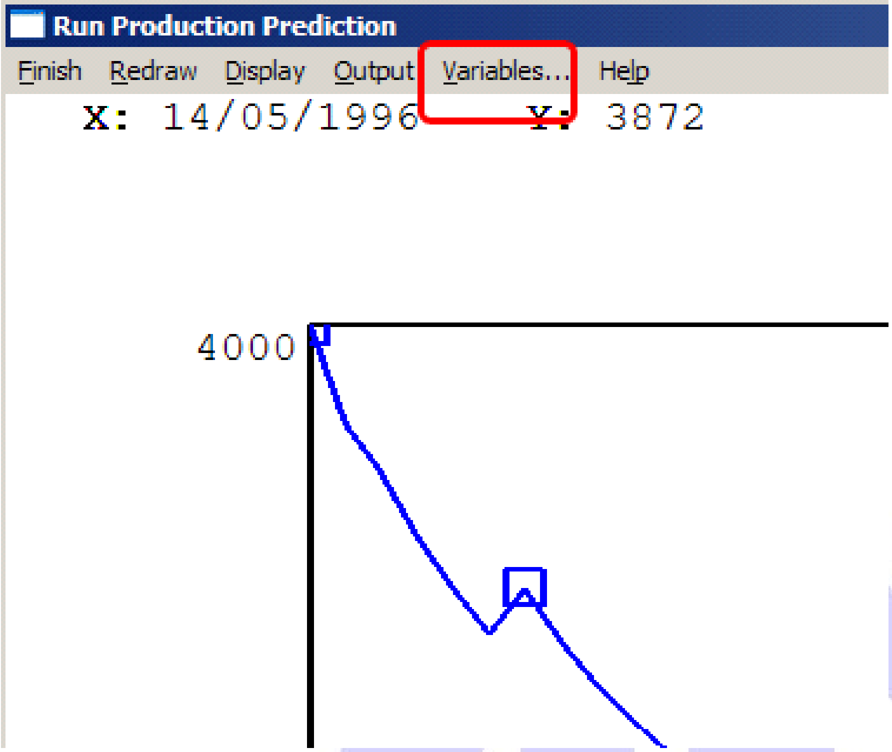


Stream: Prediction

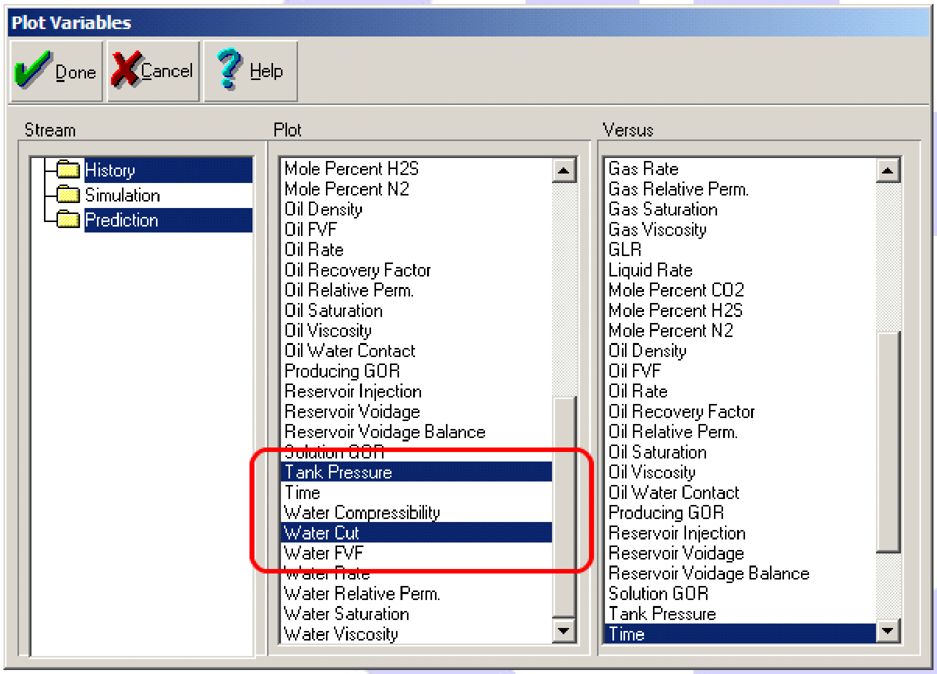
Time	Tank Pressure	Oil Recovery Factor	Oil Rate	Gas Rate	Water Rate	Liquid Rate	Avg.Oil Rate	Avg.Gas Rate	Avg.Water Rate	Avg.Liq Rate	Gas Saturation	Oil Saturation	Water Saturation	Oil FVF	Gas FVF
date d/m/y	psig	percent	STB/day	MMscf/day	STB/day	STB/day	STB/day	MMscf/day	STB/day	STB/day	fraction	fraction	fraction	RB/STB	ft3/scf
01/06/2006	2409.02	7.97285	10000	5	2187.51	12187.5	8503.84	4.25193	756.55	9260.39	0	0.800521	0.19948	1.31442	0.00713044
31/08/2006	2316.81	8.4044	10000	5	2261.25	12261.3	10000	5	2217.34	12217.3	0	0.79843	0.20157	1.31675	0.00741007
30/11/2006	2235.08	8.83595	10000	5	2341.62	12341.6	10000	5	2294.43	12294.4	0	0.796236	0.203764	1.31899	0.00768057
01/03/2007	2192.58	9.2675	10000	4.98031	2437.39	12437.4	10000	4.99627	2378.72	12378.7	0.00165101	0.792535	0.205814	1.31892	0.00783049
31/05/2007	2177.01	9.69905	10000	4.93907	2536.83	12536.8	10000	4.96358	2479.46	12479.5	0.00513449	0.787449	0.207417	1.31665	0.00788711
30/08/2007	2159.68	10.1306	10000	4.8933	2629.57	12629.6	10000	4.9203	2575.94	12575.9	0.00904192	0.782232	0.208726	1.31413	0.00795122
29/11/2007	2141.12	10.5622	10000	4.84442	2717.18	12717.2	10000	4.87314	2666.44	12666.4	0.0132676	0.776932	0.2098	1.31144	0.00802123
28/02/2008	2121.69	10.9937	10000	4.79341	2800.67	12800.7	10000	4.8233	2752.26	12752.3	0.0177373	0.771583	0.21068	1.30864	0.00809603
29/05/2008	2101.2	11.4253	10000	5.7753	2881.37	12881.4	10000	4.9479	2834.34	12834.3	0.0224304	0.76617	0.2114	1.3057	0.00817661
28/08/2008	2075.81	11.8568	10000	7.95321	2965.42	12965.4	10000	6.66162	2915.93	12915.9	0.0275994	0.760385	0.212015	1.30208	0.00827898
27/11/2008	2044.58	12.2884	10000	10.3864	3056.4	13056.4	10000	8.94693	3002.67	13002.7	0.0332521	0.754169	0.212579	1.29765	0.00840884
26/02/2009	2007.44	12.7199	10000	13.061	3156.85	13156.8	10000	11.4819	3097.39	13097.4	0.0393352	0.747529	0.213135	1.29243	0.00856928
28/05/2009	1964.3	13.1515	10000	15.9627	3269.23	13269.2	10000	14.2523	3202.6	13202.6	0.0458011	0.740481	0.213718	1.28642	0.00876419
27/08/2009	1915.12	13.583	10000	19.0747	3396.03	13396	10000	17.2431	3320.79	13320.8	0.0526052	0.733039	0.214356	1.27964	0.00899846
26/11/2009	1859.87	14.0146	10000	22.376	3539.83	13539.8	10000	20.4359	3454.46	13454.5	0.0597049	0.725224	0.215071	1.27211	0.00927818
25/02/2010	1798.53	14.4461	10000	25.8393	3703.33	13703.3	10000	23.8072	3606.24	13606.2	0.0670589	0.717061	0.21588	1.26388	0.009611
27/05/2010	1731.16	14.8777	10000	29.4289	3889.44	13889.4	10000	27.3265	3778.92	13778.9	0.0746256	0.708578	0.216796	1.25497	0.0100065
26/08/2010	1657.84	15.3092	10000	33.098	4101.27	14101.3	10000	30.9535	3975.49	13975.5	0.0823635	0.699808	0.217828	1.24545	0.0104767
25/11/2010	1578.74	15.7408	10000	36.7869	4342.21	14342.2	10000	34.6363	4199.16	14199.2	0.0902304	0.690791	0.218979	1.23537	0.0110371
24/02/2011	1494.09	16.1723	10000	40.4207	4615.87	14615.9	10000	38.3089	4453.43	14453.4	0.0981831	0.68157	0.220247	1.22481	0.0117072
26/05/2011	1404.22	16.6039	10000	43.9078	4926.17	14926.2	10000	41.8897	4742.03	14742	0.106178	0.672195	0.221627	1.21385	0.0125122
25/08/2011	1309.62	17.0354	10000	47.1398	5277.2	15277.2	10000	45.28	5068.96	15069	0.114169	0.662723	0.223108	1.20259	0.013485
24/11/2011	1210.87	17.467	10000	49.9927	5673.16	15673.2	10000	48.3646	5438.37	15438.4	0.122112	0.653215	0.224673	1.19113	0.0146686
23/02/2012	1108.78	17.8985	10000	52.3312	6118.18	16118.2	10000	51.0145	5854.45	15854.5	0.129963	0.643737	0.226299	1.17962	0.0161204
24/05/2012	1004.31	18.3301	10000	54.0149	6615.99	16616	10000	53.0914	6321.19	16321.2	0.137681	0.634361	0.227958	1.16817	0.017917
23/08/2012	898.648	18.7616	10000	54.9094	7169.5	17169.5	10000	54.4567	6842.02	16842	0.145227	0.625161	0.229612	1.15693	0.0201627
22/11/2012	793.199	19.1932	10000	54.8992	7780.13	17780.1	10000	54.9824	7419.29	17419.3	0.152572	0.616211	0.231217	1.14605	0.0230009
21/02/2013	689.545	19.6247	10000	53.9045	8447.02	18447	10000	54.5666	8053.55	18053.6	0.159695	0.607581	0.232724	1.13567	0.0266306
23/05/2013	589.415	20.0563	10000	51.8974	9165.99	19166	10000	53.1498	8742.64	18742.6	0.166588	0.599338	0.234074	1.12593	0.0313312
22/08/2013	494.58	20.4878	10000	48.917	9928.49	19928.5	10000	50.731	9480.65	19480.6	0.173257	0.591535	0.235208	1.11695	0.0374988
21/11/2013	406.738	20.9194	10000	45.0769	10720.7	20720.7	10000	47.3801	10256.9	20256.9	0.179725	0.584213	0.236062	1.10882	0.0456989
20/02/2014	327.354	21.3509	10000	40.5641	11522.9	21522.9	10000	43.2419	11055.1	21055.1	0.186027	0.577395	0.236578	1.10159	0.0567422

Step 6: Comparing the results.

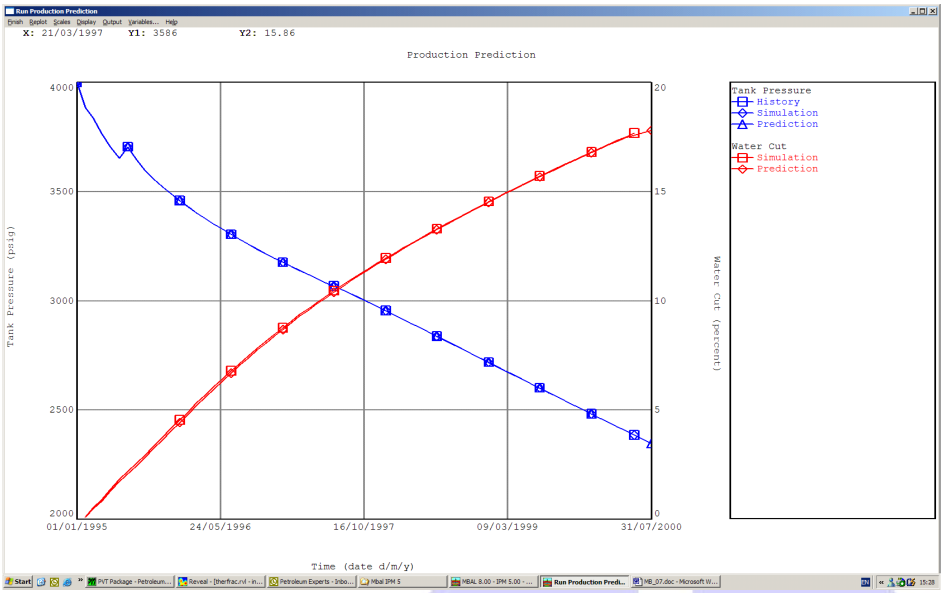
In the prediction screen the “Plot” button will show a plot of the results in terms of pressure Vs time. If the “Variables” button is selected from the menu bar of the plot, the list of plot variables will be shown:


Run Production Prediction
Finish
Redraw
Display
Output
Variables...
Help
X: 14/05/1996
Y: 3872
4000

The quality of the rel perms will be judged from the quality of the match on water production.


Plot Variables
Done
Cancel
Help
Stream
Plot
Versus
History
Simulation
Prediction
Mole Percent H2S
Mole Percent N2
Oil Density
Oil FVF
Oil Rate
Oil Recovery Factor
Oil Relative Perm.
Oil Saturation
Oil Viscosity
Oil Water Contact
Producing GOR
Reservoir Injection
Reservoir Voidage
Reservoir Voidage Balance
Solution GOR
Tank Pressure
Time
Water Compressibility
Water Cut
Water FVF
Water Rate
Water Relative Perm.
Water Saturation
Water Viscosity
Gas Rate
Gas Relative Perm.
Gas Saturation
Gas Viscosity
GLR
Liquid Rate
Mole Percent CO2
Mole Percent H2S
Mole Percent N2
Oil Density
Oil FVF
Oil Rate
Oil Recovery Factor
Oil Relative Perm.
Oil Saturation
Oil Viscosity
Oil Water Contact
Producing GOR
Reservoir Injection
Reservoir Voidage
Reservoir Voidage Balance
Solution GOR
Tank Pressure
Time

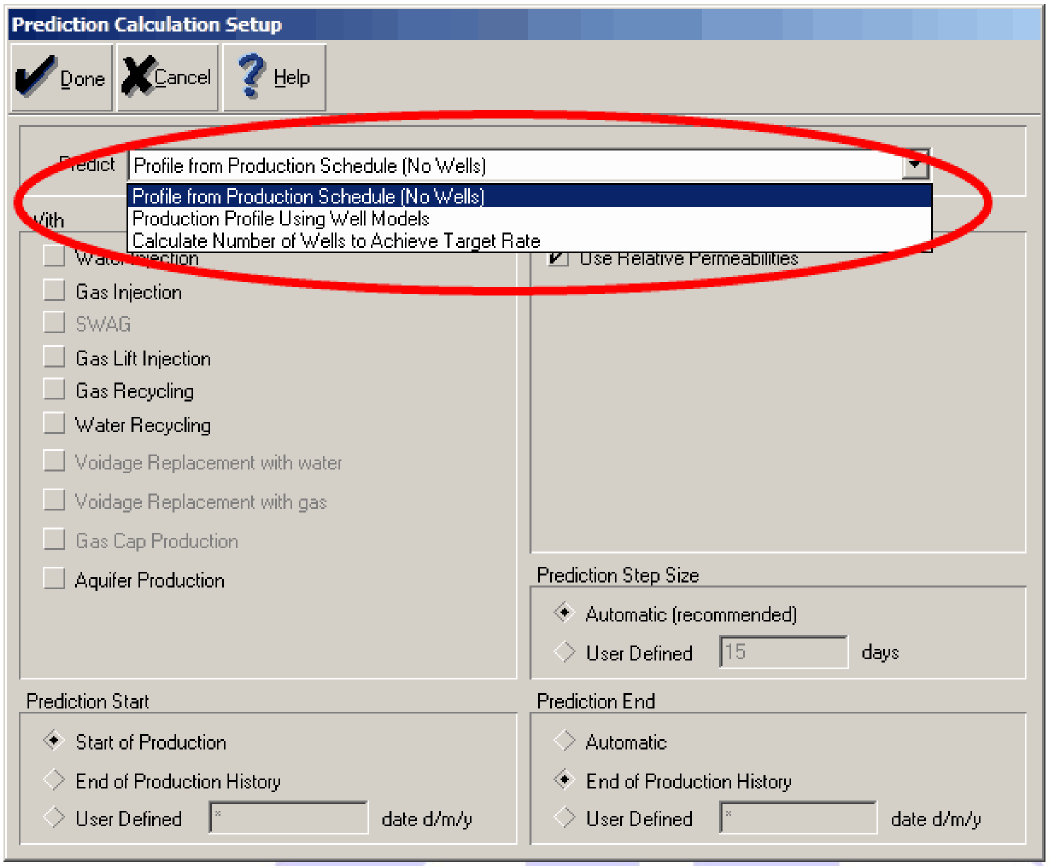
Select both the history, and prediction streams to be plotted together:


Run Production Prediction
Finish Replot Scales Display Output Variables... Help
X: 21/03/1997 Y1: 3586 Y2: 15.86
Production Prediction
Tank Pressure (psig)
4000
3500
3000
2500
2000
01/01/1995
24/05/1996
16/10/1997
09/03/1999
31/07/2000
Time (date d/m/y)
20
15
10
5
0
Water Cut (percent)
Tank Pressure
History
Simulation
Prediction
Water Cut
Simulation
Prediction

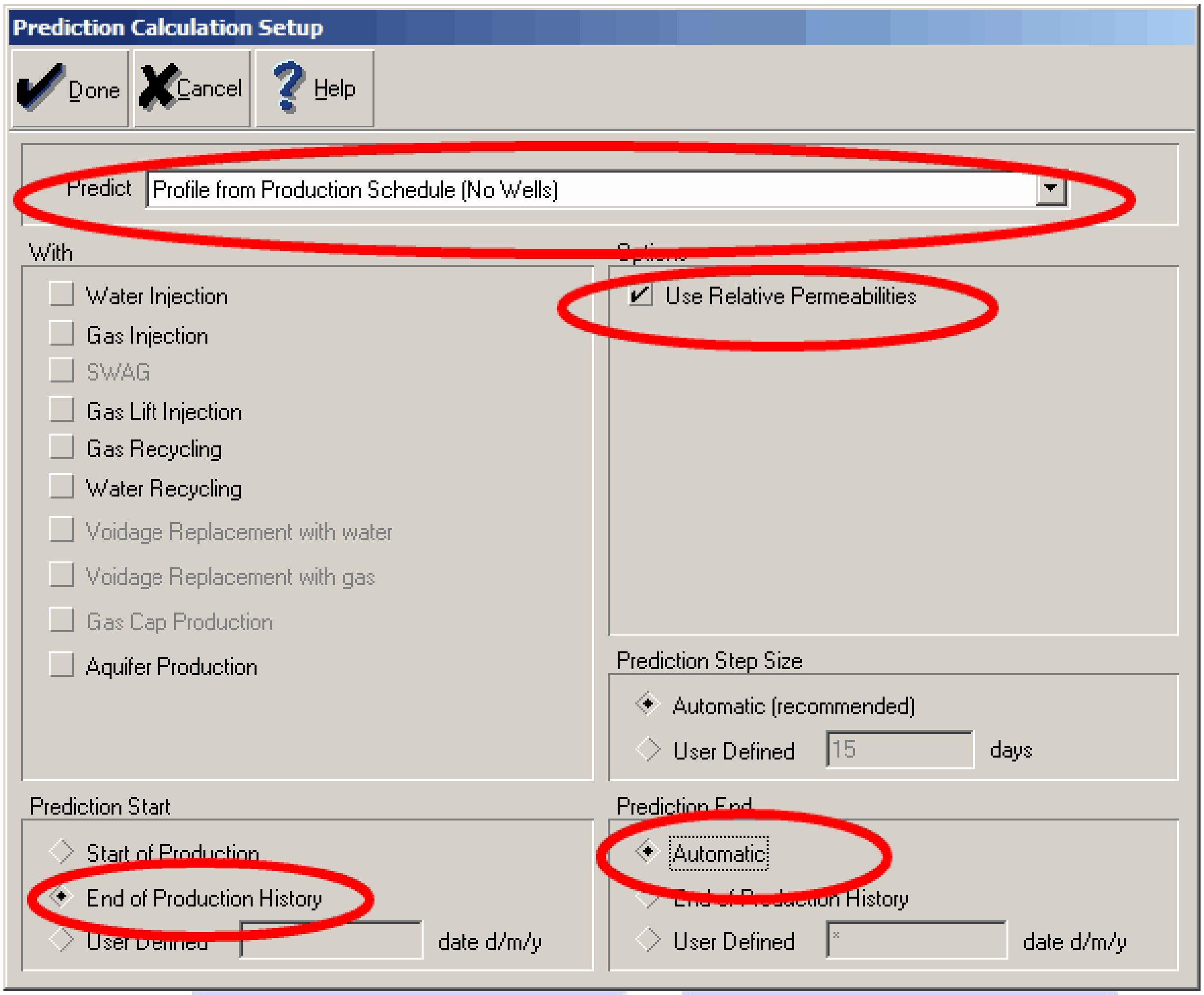
Where we can see a good agreement between the data and the forecast, this illustrates that the model is ready for predictions.

3.1.4.3 Predicting reservoir pressure decline without a well

In **MBAL** there are various options for performing a forecast. The three main sub-groups for an oil system are highlighted below:


Prediction Calculation Setup
Done
Cancel
Help
Predict
Profile from Production Schedule (No Wells)
Profile from Production Schedule (No Wells)
Production Profile Using Well Models
Calculate Number of Wells to Achieve Target Rate
With
☐ Water Injection
☐ Gas Injection
☐ SWAG
☐ Gas Lift Injection
☐ Gas Recycling
☐ Water Recycling
☐ Voidage Replacement with water
☐ Voidage Replacement with gas
☐ Gas Cap Production
☐ Aquifer Production
☑ Use Relative Permeabilities
Prediction Step Size
● Automatic (recommended)
○ User Defined
15
days
Prediction Start
● Start of Production
○ End of Production History
○ User Defined
date d/m/y
Prediction End
○ Automatic
● End of Production History
○ User Defined
date d/m/y

The first option allows a forecast without a well whereas the second requires a forecast with a well model. In this subsection we will look into a forecast without a well and in the next subsection a forecast with a well model will be performed.
Having selected the relevant options and selecting 'Done':


Prediction Calculation Setup

Predict: Profile from Production Schedule (No Wells)

With:
- ☐ Water Injection
- ☐ Gas Injection
- ☐ SWAG
- ☐ Gas Lift Injection
- ☐ Gas Recycling
- ☐ Water Recycling
- ☐ Voidage Replacement with water
- ☐ Voidage Replacement with gas
- ☐ Gas Cap Production
- ☐ Aquifer Production

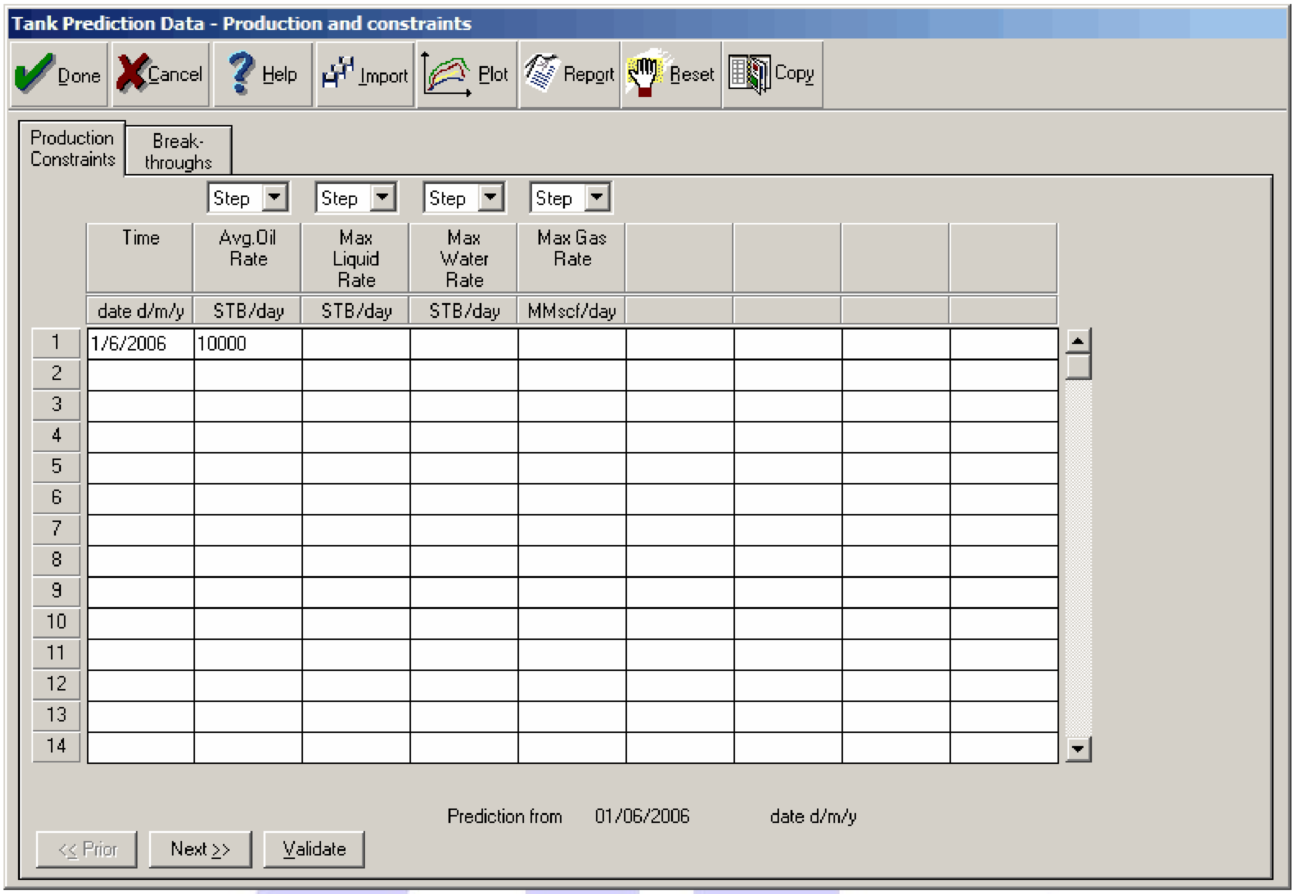
Options:
- ☑ Use Relative Permeabilities

Prediction Step Size:
- ● Automatic (recommended)
- ○ User Defined 15 days

Prediction Start:
- ○ Start of Production
- ● End of Production History
- ○ User Defined date d/m/y

Prediction End:
- ● Automatic
- ○ End of Production History
- ○ User Defined date d/m/y

The main screen will once again be viewed, at this stage Production Prediction|Production and 'Constraints' can be selected to enter the desired production of oil:

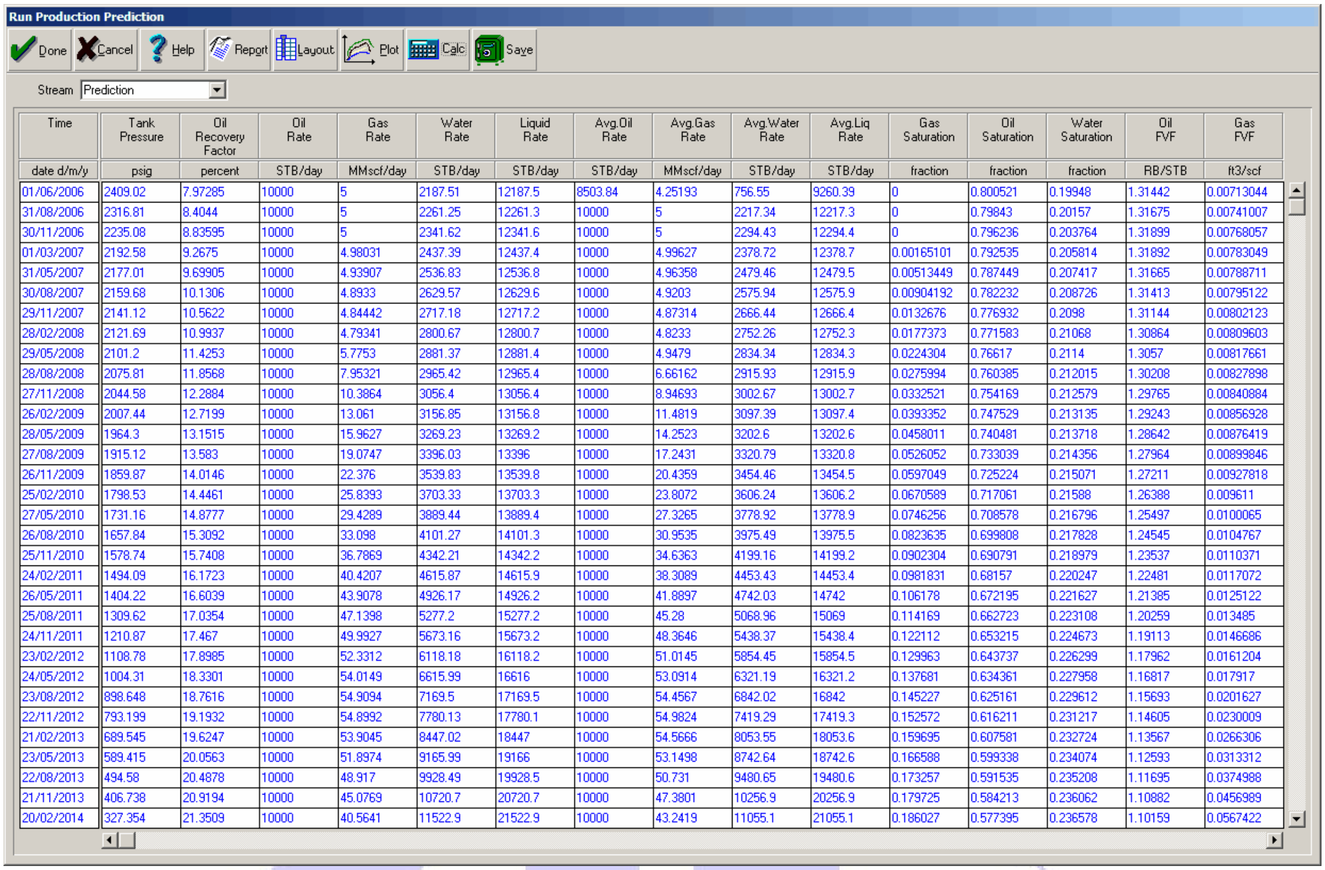

Tank Prediction Data - Production and constraints
Done
Cancel
Help
Import
Plot
Report
Reset
Copy
Production Constraints
Break-throughs
Step
Step
Step
Step
<< Prior
Next >>
Validate

	Time	Avg.Oil Rate	Max Liquid Rate	Max Water Rate	Max Gas Rate				
	date d/m/y	STB/day	STB/day	STB/day	MMscf/day				
1	1/6/2006	10000							
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									

Prediction from 01/06/2006 date d/m/y

This production will be kept constant throughout the prediction, until the reservoir does not have enough energy to support it.

Performing the forecast now:



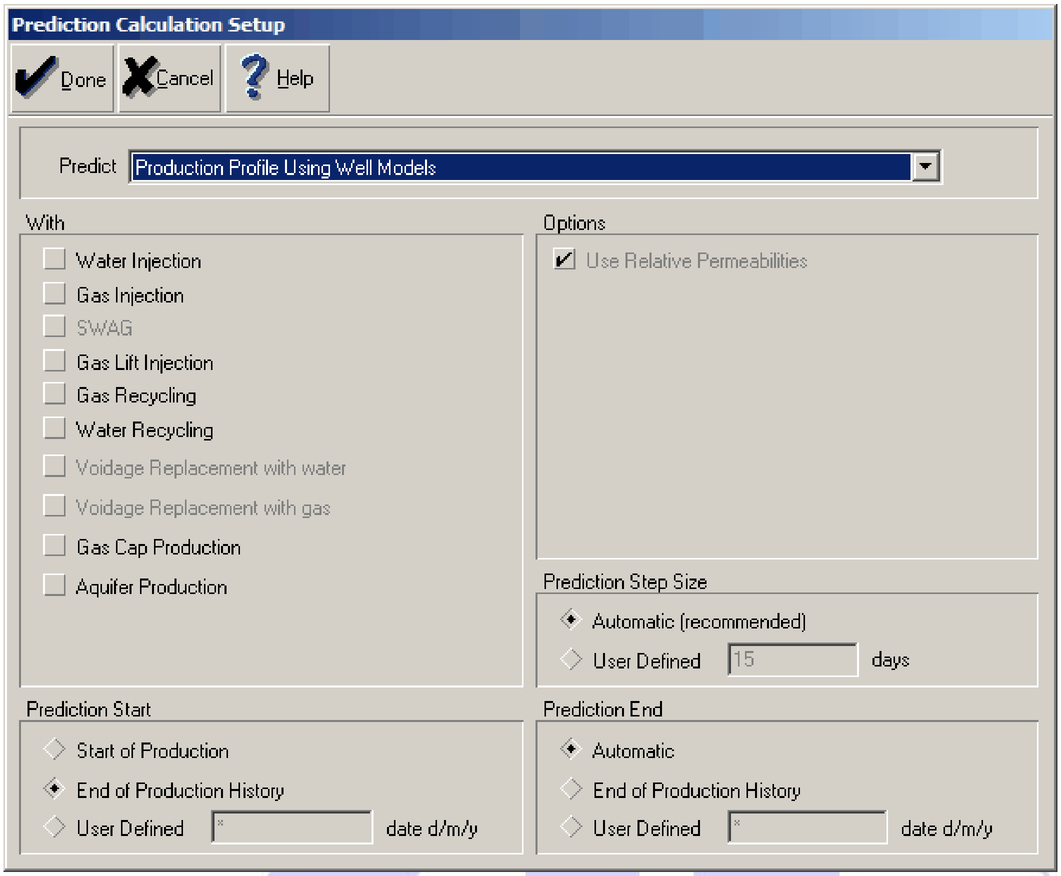
Stream: Prediction

Time	Tank Pressure	Oil Recovery Factor	Oil Rate	Gas Rate	Water Rate	Liquid Rate	Avg.Oil Rate	Avg.Gas Rate	Avg.Water Rate	Avg.Liq Rate	Gas Saturation	Oil Saturation	Water Saturation	Oil FVF	Gas FVF
date d/m/y	psig	percent	STB/day	MMscf/day	STB/day	STB/day	STB/day	MMscf/day	STB/day	STB/day	fraction	fraction	fraction	RB/STB	ft3/scf
01/06/2006	2409.02	7.97285	10000	5	2187.51	12187.5	8503.84	4.25193	756.55	9260.39	0	0.800521	0.19948	1.31442	0.00713044
31/08/2006	2316.81	8.4044	10000	5	2261.25	12261.3	10000	5	2217.34	12217.3	0	0.79843	0.20157	1.31675	0.00741007
30/11/2006	2235.08	8.83595	10000	5	2341.62	12341.6	10000	5	2294.43	12294.4	0	0.796236	0.203764	1.31899	0.00768057
01/03/2007	2192.58	9.2675	10000	4.98031	2437.39	12437.4	10000	4.99627	2378.72	12378.7	0.00165101	0.792535	0.205814	1.31892	0.00783049
31/05/2007	2177.01	9.69905	10000	4.93907	2536.83	12536.8	10000	4.96358	2479.46	12479.5	0.00513449	0.787449	0.207417	1.31665	0.00788711
30/08/2007	2159.68	10.1306	10000	4.8933	2629.57	12629.6	10000	4.9203	2575.94	12575.9	0.00904192	0.782232	0.208726	1.31413	0.00795122
29/11/2007	2141.12	10.5622	10000	4.84442	2717.18	12717.2	10000	4.87314	2666.44	12666.4	0.0132676	0.776932	0.2098	1.31144	0.00802123
28/02/2008	2121.69	10.9937	10000	4.79341	2800.67	12800.7	10000	4.8233	2752.26	12752.3	0.0177373	0.771583	0.21068	1.30864	0.00809603
29/05/2008	2101.2	11.4253	10000	5.7753	2881.37	12881.4	10000	4.9479	2834.34	12834.3	0.0224304	0.76617	0.2114	1.3057	0.00817661
28/08/2008	2075.81	11.8568	10000	7.95321	2965.42	12965.4	10000	6.66162	2915.93	12915.9	0.0275994	0.760385	0.212015	1.30208	0.00827898
27/11/2008	2044.58	12.2884	10000	10.3864	3056.4	13056.4	10000	8.94693	3002.67	13002.7	0.0332521	0.754169	0.212579	1.29765	0.00840884
26/02/2009	2007.44	12.7199	10000	13.061	3156.85	13156.8	10000	11.4819	3097.39	13097.4	0.0393352	0.747529	0.213135	1.29243	0.00856928
28/05/2009	1964.3	13.1515	10000	15.9627	3269.23	13269.2	10000	14.2523	3202.6	13202.6	0.0458011	0.740481	0.213718	1.28642	0.00876419
27/08/2009	1915.12	13.583	10000	19.0747	3396.03	13396	10000	17.2431	3320.79	13320.8	0.0526052	0.733039	0.214356	1.27964	0.00899846
26/11/2009	1859.87	14.0146	10000	22.376	3539.83	13539.8	10000	20.4359	3454.46	13454.5	0.0597049	0.725224	0.215071	1.27211	0.00927818
25/02/2010	1798.53	14.4461	10000	25.8393	3703.33	13703.3	10000	23.8072	3606.24	13606.2	0.0670589	0.717061	0.21588	1.26388	0.009611
27/05/2010	1731.16	14.8777	10000	29.4289	3889.44	13889.4	10000	27.3265	3778.92	13778.9	0.0746256	0.708578	0.216796	1.25497	0.0100065
26/08/2010	1657.84	15.3092	10000	33.098	4101.27	14101.3	10000	30.9535	3975.49	13975.5	0.0823635	0.699808	0.217828	1.24545	0.0104767
25/11/2010	1578.74	15.7408	10000	36.7869	4342.21	14342.2	10000	34.6363	4199.16	14199.2	0.0902304	0.690791	0.218979	1.23537	0.0110371
24/02/2011	1494.09	16.1723	10000	40.4207	4615.87	14615.9	10000	38.3089	4453.43	14453.4	0.0981831	0.68157	0.220247	1.22481	0.0117072
26/05/2011	1404.22	16.6039	10000	43.9078	4926.17	14926.2	10000	41.8897	4742.03	14742	0.106178	0.672195	0.221627	1.21385	0.0125122
25/08/2011	1309.62	17.0354	10000	47.1398	5277.2	15277.2	10000	45.28	5068.96	15069	0.114169	0.662723	0.223108	1.20259	0.013485
24/11/2011	1210.87	17.467	10000	49.9927	5673.16	15673.2	10000	48.3646	5438.37	15438.4	0.122112	0.653215	0.224673	1.19113	0.0146686
23/02/2012	1108.78	17.8985	10000	52.3312	6118.18	16118.2	10000	51.0145	5854.45	15854.5	0.129963	0.643737	0.226299	1.17962	0.0161204
24/05/2012	1004.31	18.3301	10000	54.0149	6615.99	16616	10000	53.0914	6321.19	16321.2	0.137681	0.634361	0.227958	1.16817	0.017917
23/08/2012	898.648	18.7616	10000	54.9094	7169.5	17169.5	10000	54.4567	6842.02	16842	0.145227	0.625161	0.229612	1.15693	0.0201627
22/11/2012	793.199	19.1932	10000	54.8992	7780.13	17780.1	10000	54.9824	7419.29	17419.3	0.152572	0.616211	0.231217	1.14605	0.0230009
21/02/2013	689.545	19.6247	10000	53.9045	8447.02	18447	10000	54.5666	8053.55	18053.6	0.159695	0.607581	0.232724	1.13567	0.0266306
23/05/2013	589.415	20.0563	10000	51.8974	9165.99	19166	10000	53.1498	8742.64	18742.6	0.166588	0.599338	0.234074	1.12593	0.0313312
22/08/2013	494.58	20.4878	10000	48.917	9928.49	19928.5	10000	50.731	9480.65	19480.6	0.173257	0.591535	0.235208	1.11695	0.0374988
21/11/2013	406.738	20.9194	10000	45.0769	10720.7	20720.7	10000	47.3801	10256.9	20256.9	0.179725	0.584213	0.236062	1.10882	0.0456989
20/02/2014	327.354	21.3509	10000	40.5641	11522.9	21522.9	10000	43.2419	11055.1	21055.1	0.186027	0.577395	0.236578	1.10159	0.0567422

The results indicate that the reservoir can only support this production for a only a few more years. Please note that the oil rate is constant, as specified by the user, at 10000bbls/day.

3.1.4.4 Predicting production and reservoir pressure decline with a well model

Having ensured that the 'Production Profile Using Well Models' was defined in the 'Options' menu:


Prediction Calculation Setup
Done
Cancel
Help

Predict: Production Profile Using Well Models

With
- ☐ Water Injection
- ☐ Gas Injection
- ☐ SWAG
- ☐ Gas Lift Injection
- ☐ Gas Recycling
- ☐ Water Recycling
- ☐ Voidage Replacement with water
- ☐ Voidage Replacement with gas
- ☐ Gas Cap Production
- ☐ Aquifer Production

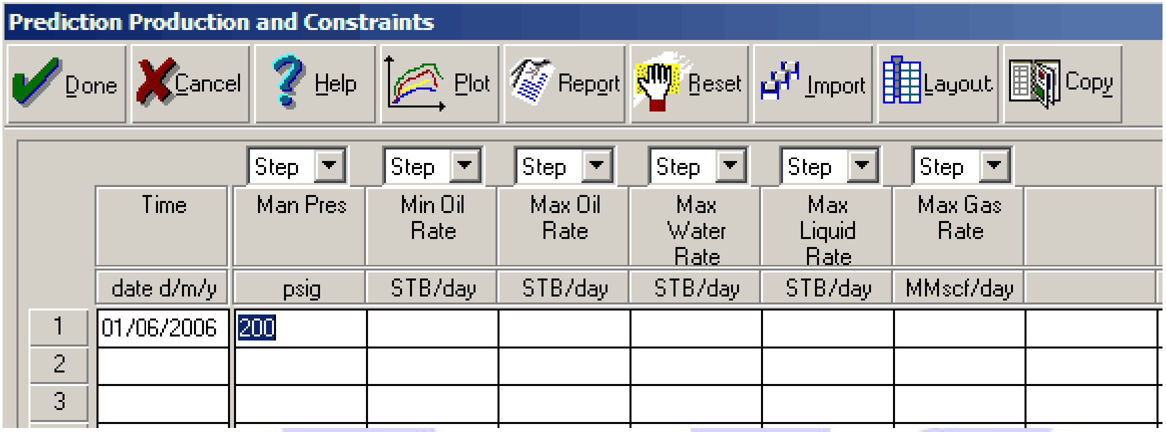
Options
- ☑ Use Relative Permeabilities

Prediction Step Size
- ● Automatic (recommended)
- ○ User Defined 15 days

Prediction Start
- ○ Start of Production
- ● End of Production History
- ○ User Defined date d/m/y

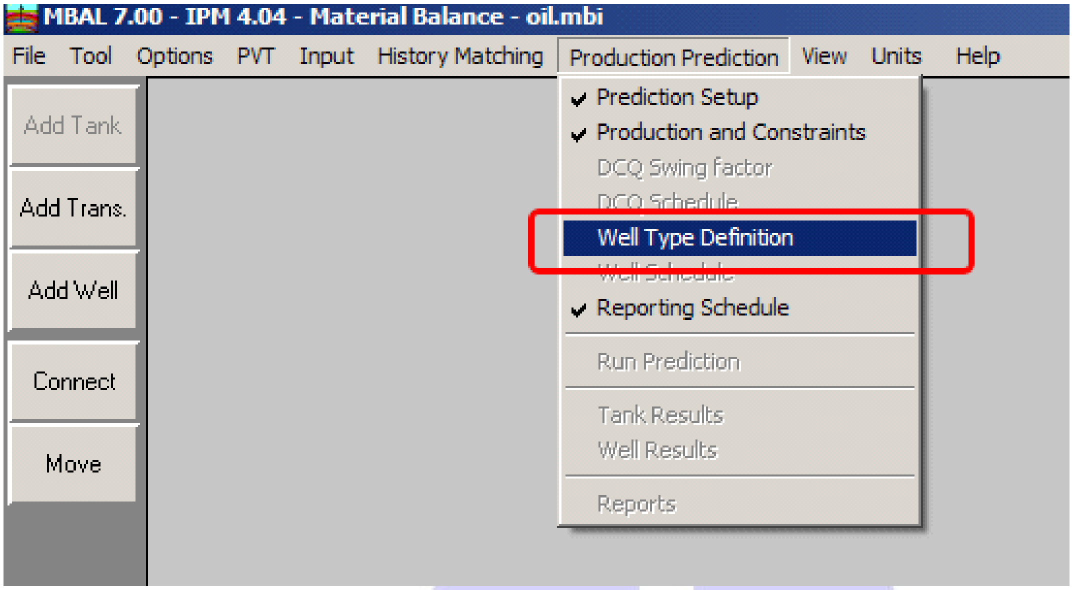
Prediction End
- ● Automatic
- ○ End of Production History
- ○ User Defined date d/m/y

In the 'Production and Constraints' screen different constraints are now required which correspond to the presence of the well; the well head pressure now needs to be specified:

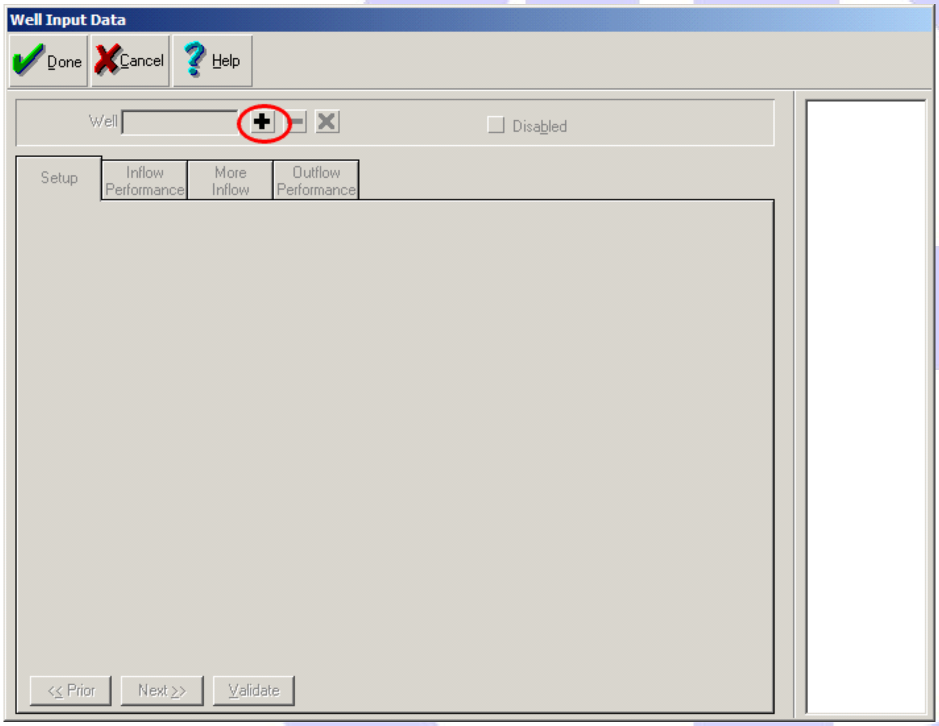

Prediction Production and Constraints
Done
Cancel
Help
Plot
Report
Reset
Import
Layout
Copy

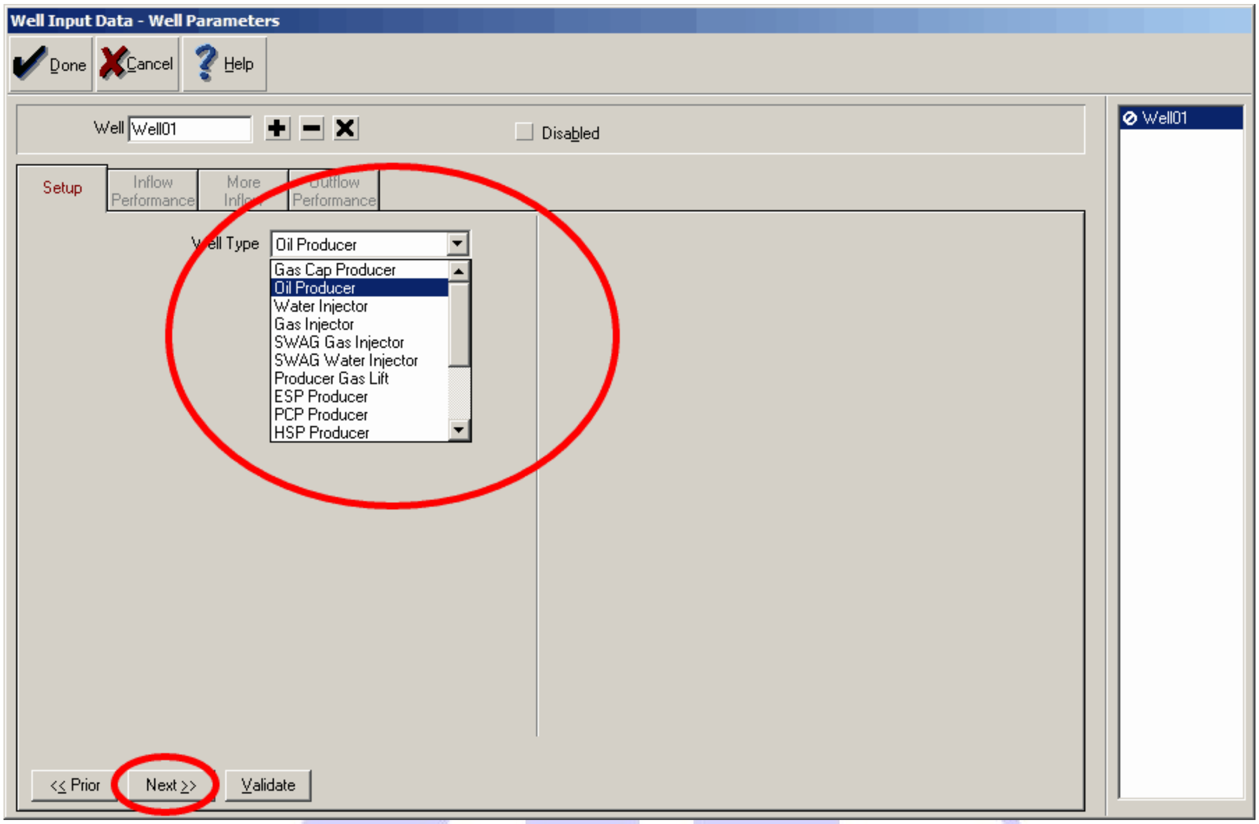
		Step	Step	Step	Step	Step	Step
	Time	Man Pres	Min Oil Rate	Max Oil Rate	Max Water Rate	Max Liquid Rate	Max Gas Rate
	date d/m/y	psig	STB/day	STB/day	STB/day	STB/day	MMscf/day
1	01/06/2006	200					
2							
3							

The next option relates to the well type definition:


MBAL 7.00 - IPM 4.04 - Material Balance - oil.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Add Tank
Add Trans.
Add Well
Connect
Move
Prediction Setup
Production and Constraints
DCQ Swing factor
DCQ Schedule
Well Type Definition
Well Schedule
Reporting Schedule
Run Prediction
Tank Results
Well Results
Reports

Selecting the '+' button will add a well in the model:

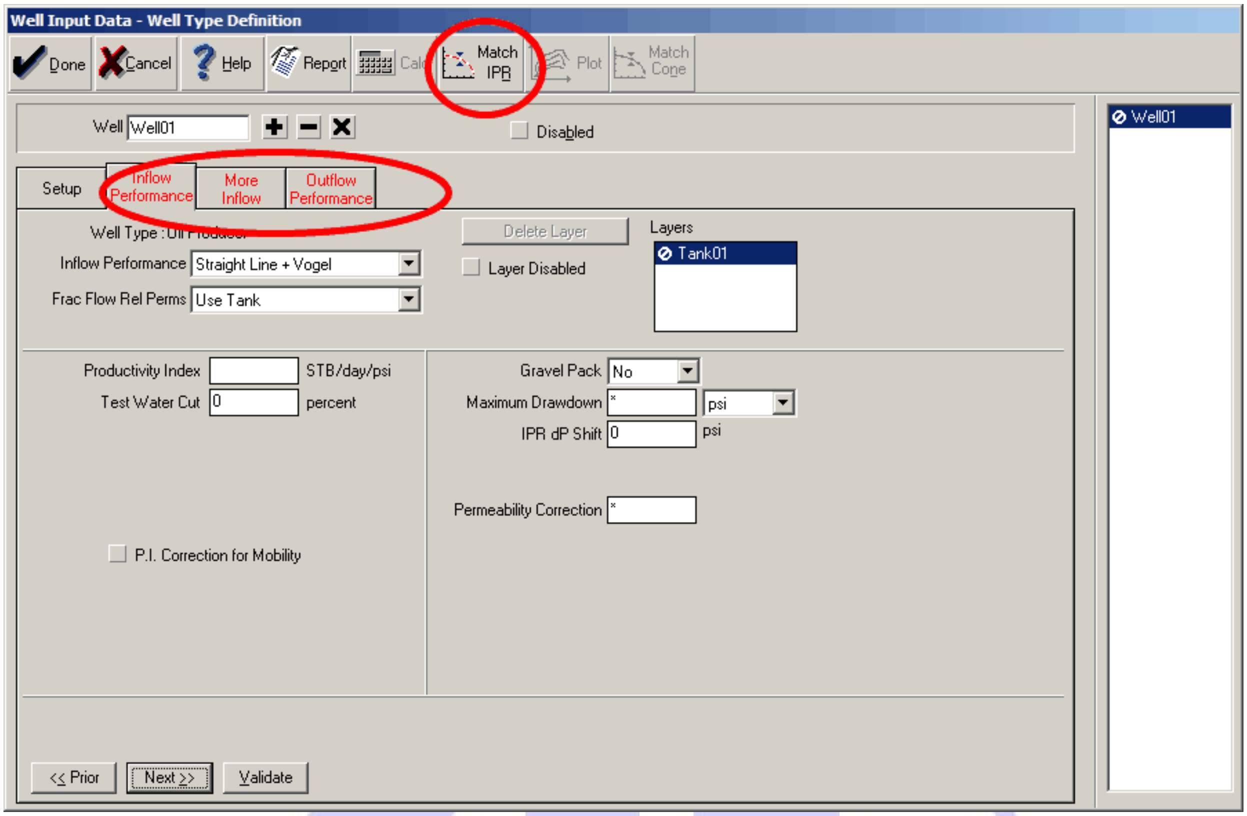

Well Input Data
Done
Cancel
Help
Well
Disabled
Setup
Inflow Performance
More Inflow
Outflow Performance
<< Prior
Next >>
Validate


Well Input Data - Well Parameters
Done
Cancel
Help
Disabled
Setup
Inflow Performance
More Inflow
Outflow Performance
Gas Cap Producer
Oil Producer
Water Injector
Gas Injector
SWAG Gas Injector
SWAG Water Injector
Producer Gas Lift
ESP Producer
PCP Producer
HSP Producer
<< Prior
Next >>
Validate
Well01

Well Well01

Well Type Oil Producer

As shown in the screen above the type of well can now be defined, in this case a naturally flowing oil producer. Having done this, then the inflow and outflow for this well can be defined:


Well Input Data - Well Type Definition
Done
Cancel
Help
Report
Calc
Match IPR
Plot
Match Cone
Setup
Inflow Performance
More Inflow
Outflow Performance
Delete Layer
<< Prior
Next >>
Validate

Well: Well01

☐ Disabled

Well Type : Oil Producer

Inflow Performance: Straight Line + Vogel

Frac Flow Rel Perms: Use Tank

☐ Layer Disabled

Layers: Tank01

Productivity Index: STB/day/psi

Test Water Cut: 0 percent

☐ P.I. Correction for Mobility

Gravel Pack: No

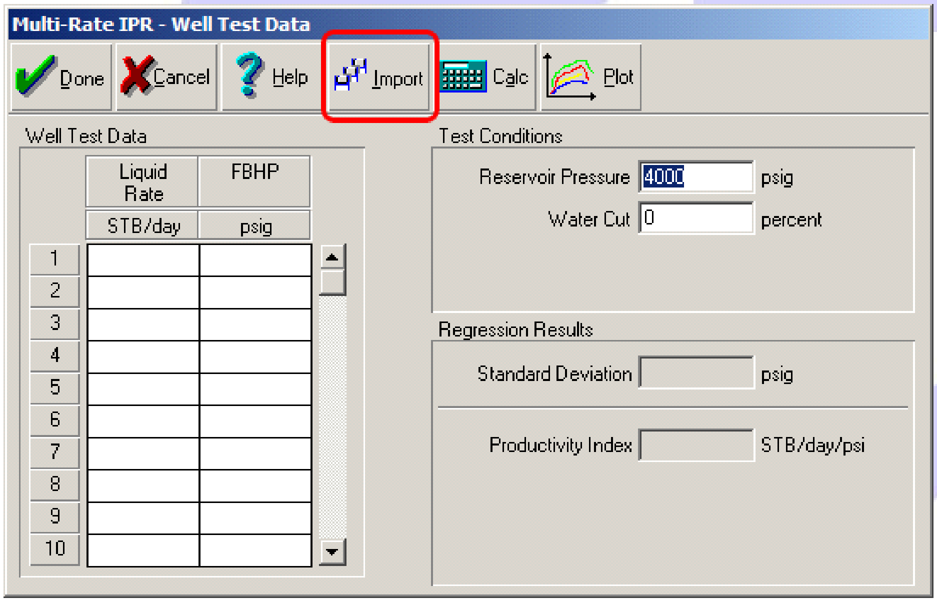
Maximum Drawdown: * psi

IPR dP Shift: 0 psi

Permeability Correction: *

Well01

An IPR model can be created in **PROSPER**. Assuming that the PI of the well is not known, **PROSPER** can export a *.mip file with all the inflow information needed for **MBAL** to calculate the PI. Selecting the “Match IPR” button as shown above will prompt the IPR matching screen. The MIP file can be then imported:


Multi-Rate IPR - Well Test Data
Done
Cancel
Help
Import
Calc
Plot

Well Test Data

	Liquid Rate	FBHP
	STB/day	psig
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Test Conditions

Reservoir Pressure: 4000 psig

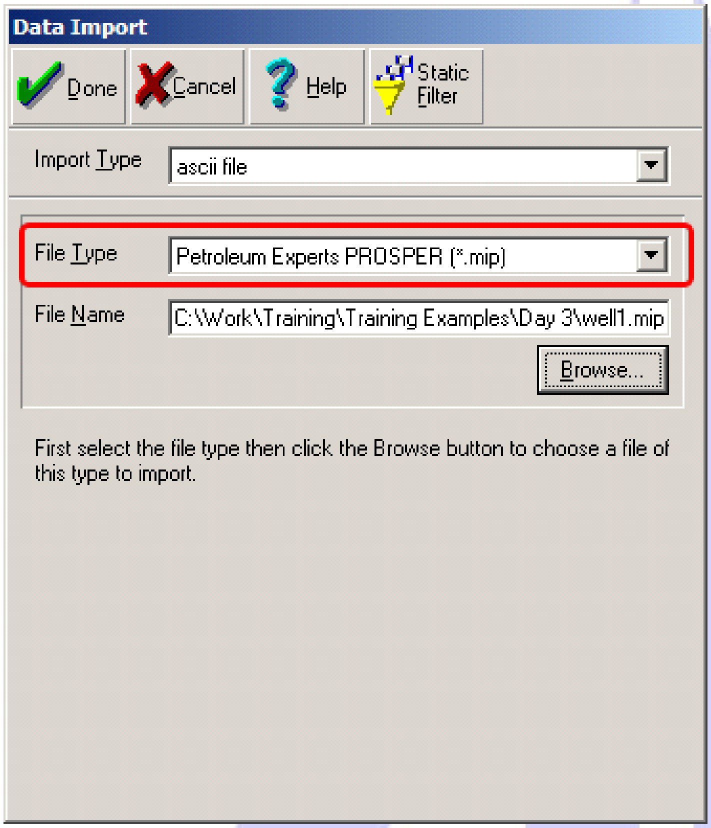
Water Cut: 0 percent

Regression Results

Standard Deviation: psig

Productivity Index: STB/day/psi

Select the file from the relevant directory as shown below:


Data Import
Done
Cancel
Help
Static Filter
Browse...

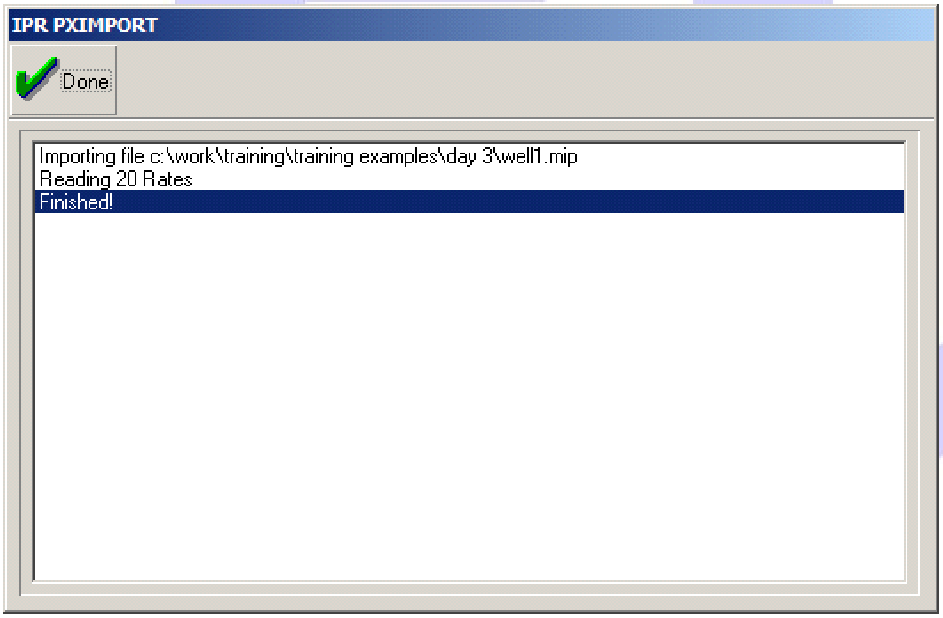
Import Type: ascii file

File Type: Petroleum Experts PROSPER (*.mip)

File Name: C:\Work\Training\Training Examples\Day 3\well1.mip

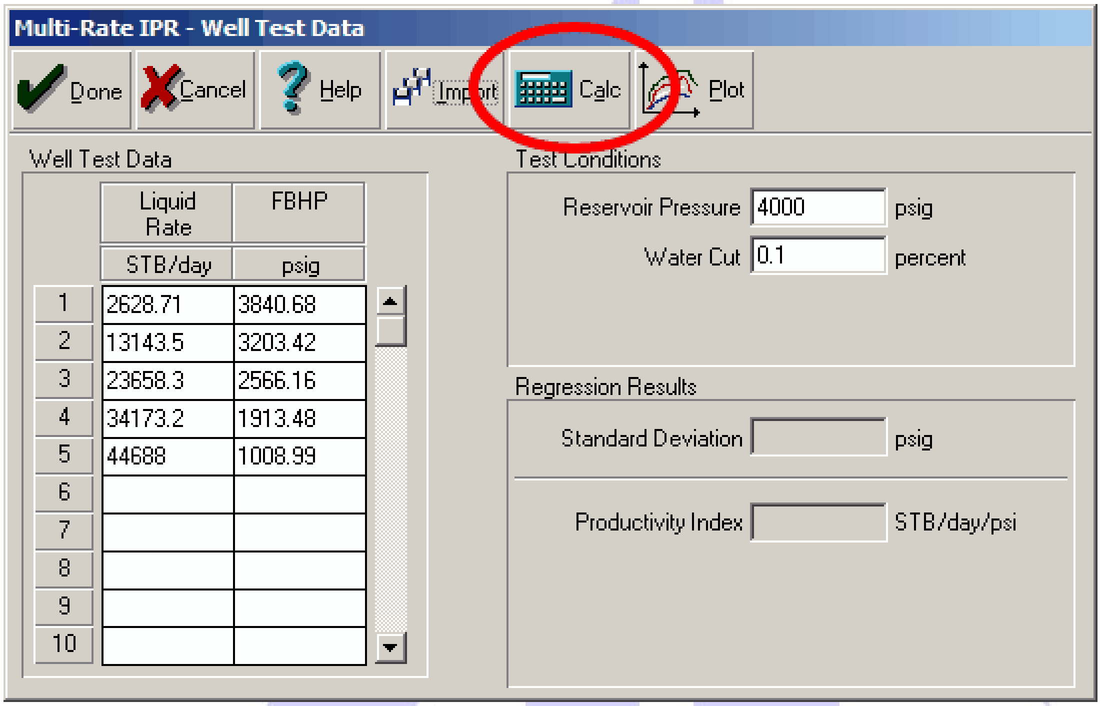
First select the file type then click the Browse button to choose a file of this type to import.

Selecting "Done" will allow **MBAL** to import the file. As soon as this is finished, the following message will appear:


IPR PXIMPORT
Done

```
Importing file c:\work\training\training examples\day 3\well1.mip
Reading 20 Rates
Finished!
```

The .mip file has allowed **MBAL** to pick up the reservoir pressure, WC and test data from the **PROSPER** file. Clicking on the "Calc" button will match this data to a PI and Vogel model:



Multi-Rate IPR - Well Test Data

Well Test Data

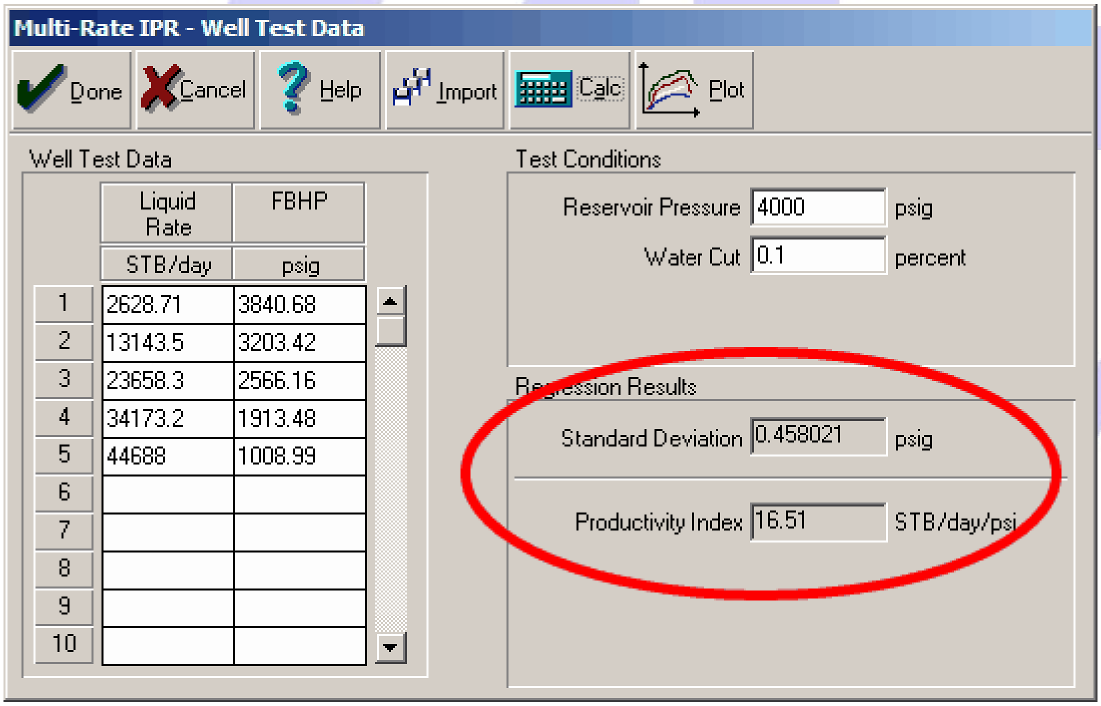
	Liquid Rate	FBHP
	STB/day	psig
1	2628.71	3840.68
2	13143.5	3203.42
3	23658.3	2566.16
4	34173.2	1913.48
5	44688	1008.99
6		
7		
8		
9		
10		

Test Conditions

Reservoir Pressure 4000 psig
Water Cut 0.1 percent

Regression Results

Standard Deviation psig
Productivity Index STB/day/psi



Multi-Rate IPR - Well Test Data

Well Test Data

	Liquid Rate	FBHP
	STB/day	psig
1	2628.71	3840.68
2	13143.5	3203.42
3	23658.3	2566.16
4	34173.2	1913.48
5	44688	1008.99
6		
7		
8		
9		
10		

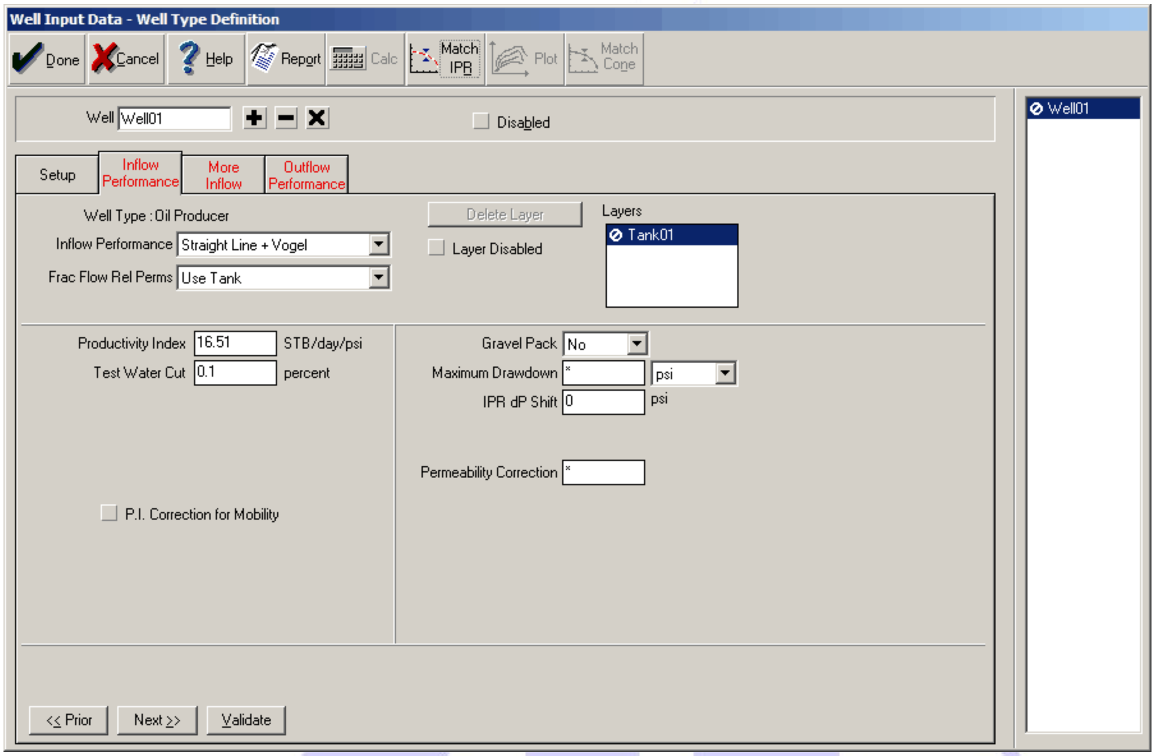
Test Conditions

Reservoir Pressure 4000 psig
Water Cut 0.1 percent

Regression Results

Standard Deviation 0.458021 psig
Productivity Index 16.51 STB/day/psi

Selecting the “Done” button will allow the calculated PI onto the well model:


Well Input Data - Well Type Definition
Done
Cancel
Help
Report
Calc
Match IPR
Plot
Match Cone
Setup
Inflow Performance
More Inflow
Outflow Performance
Delete Layer
Layers
Tank01
Well01
<< Prior
Next >>
Validate

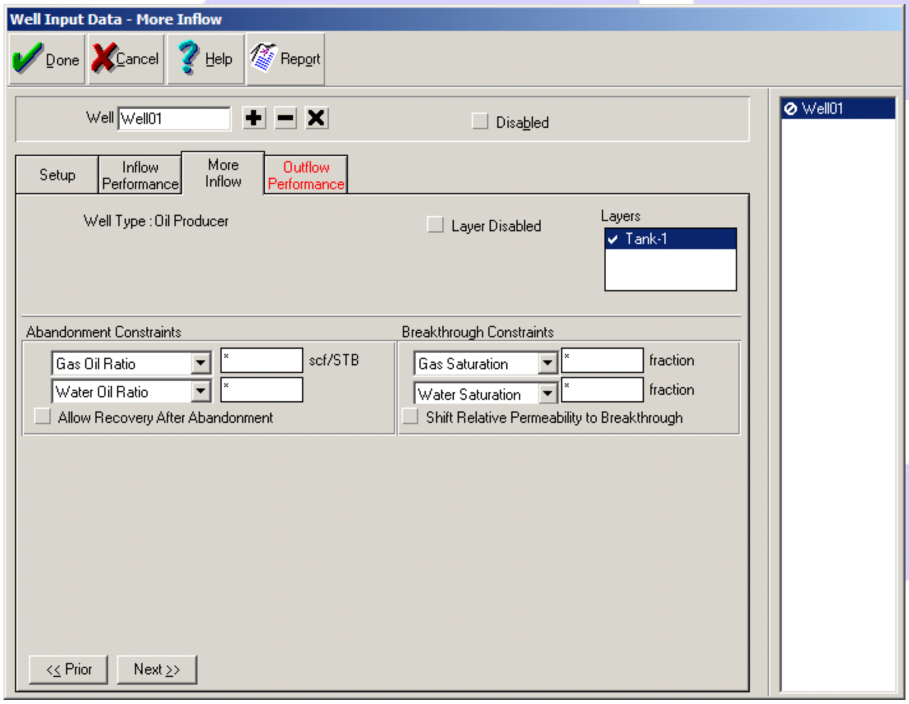
Well: Well01
☐ Disabled

Well Type : Oil Producer
Inflow Performance: Straight Line + Vogel
Frac Flow Rel Perms: Use Tank
☐ Layer Disabled

Productivity Index: 16.51 STB/day/psi
Test Water Cut: 0.1 percent
☐ P.I. Correction for Mobility

Gravel Pack: No
Maximum Drawdown: * psi
IPR dP Shift: 0 psi
Permeability Correction: *

Having populated the IPR screen with the relevant data, the “More Inflow” screen can be selected now:


Well Input Data - More Inflow
Done
Cancel
Help
Report
Setup
Inflow Performance
More Inflow
Outflow Performance
Layers
Tank-1
Well01
<< Prior
Next >>

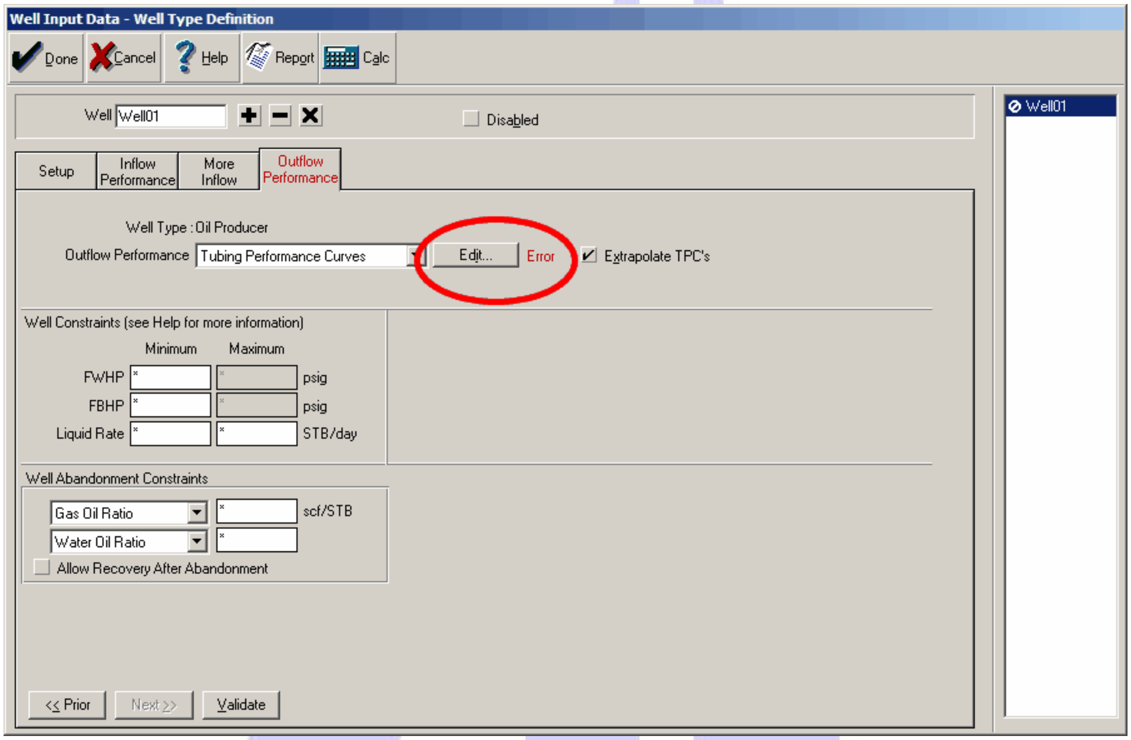
Well: Well01
☐ Disabled

Well Type : Oil Producer
☐ Layer Disabled

Abandonment Constraints
Gas Oil Ratio: * scf/STB
Water Oil Ratio: *
☐ Allow Recovery After Abandonment

Breakthrough Constraints
Gas Saturation: * fraction
Water Saturation: * fraction
☐ Shift Relative Permeability to Breakthrough

Abandonment or breakthrough constraints can be added to the well model if necessary. Moving onto the 'Outflow Performance' screen:


Well Input Data - Well Type Definition
Done
Cancel
Help
Report
Calc
Setup
Inflow Performance
More Inflow
Outflow Performance
Edit...
Well01
<< Prior
Next >>
Validate

Well Well01

☐ Disabled

Well Type : Oil Producer

Outflow Performance: Tubing Performance Curves Error

☑ Extrapolate TPC's

Well Constraints (see Help for more information)

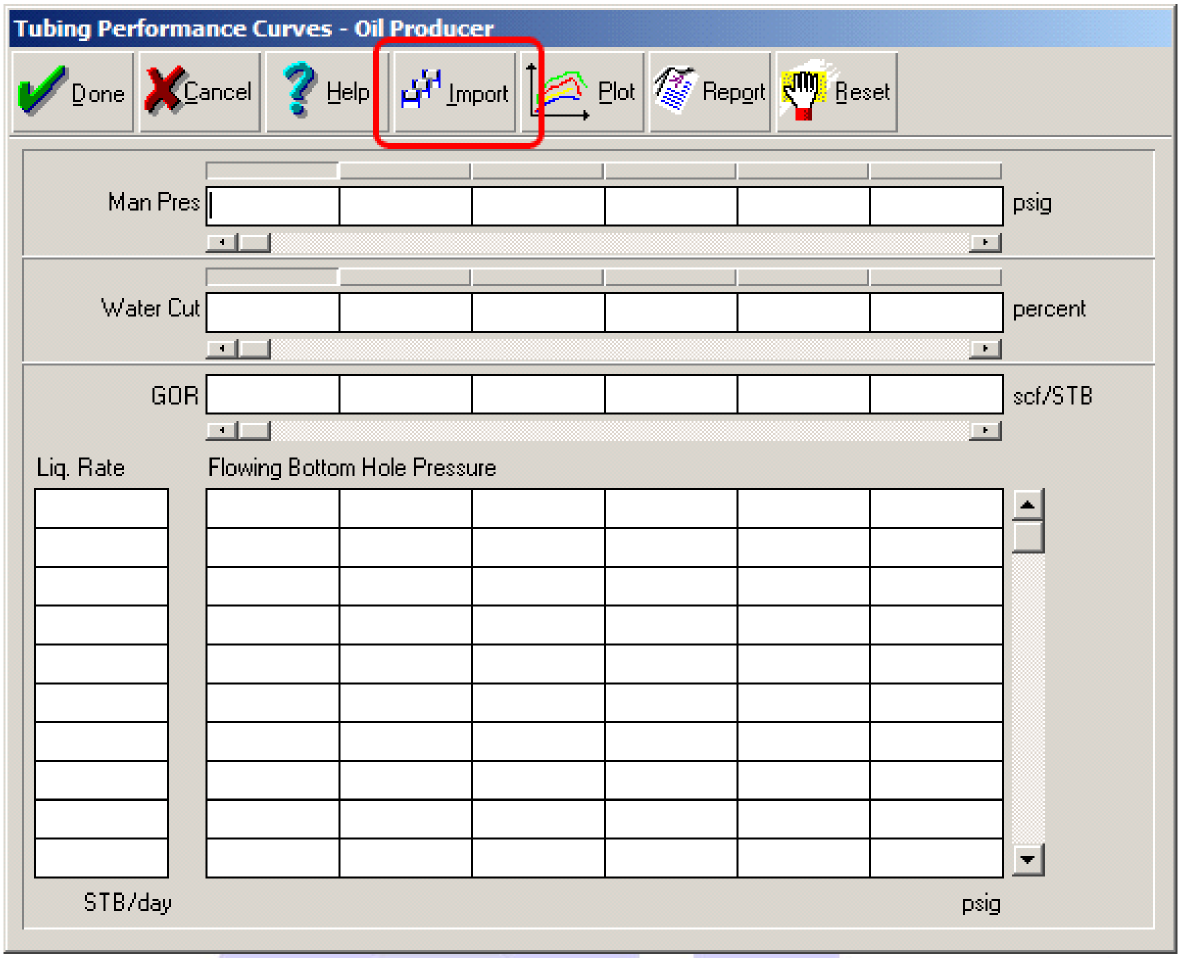
	Minimum	Maximum	
FWHP	*	*	psig
FBHP	*	*	psig
Liquid Rate	*	*	STB/day

Well Abandonment Constraints

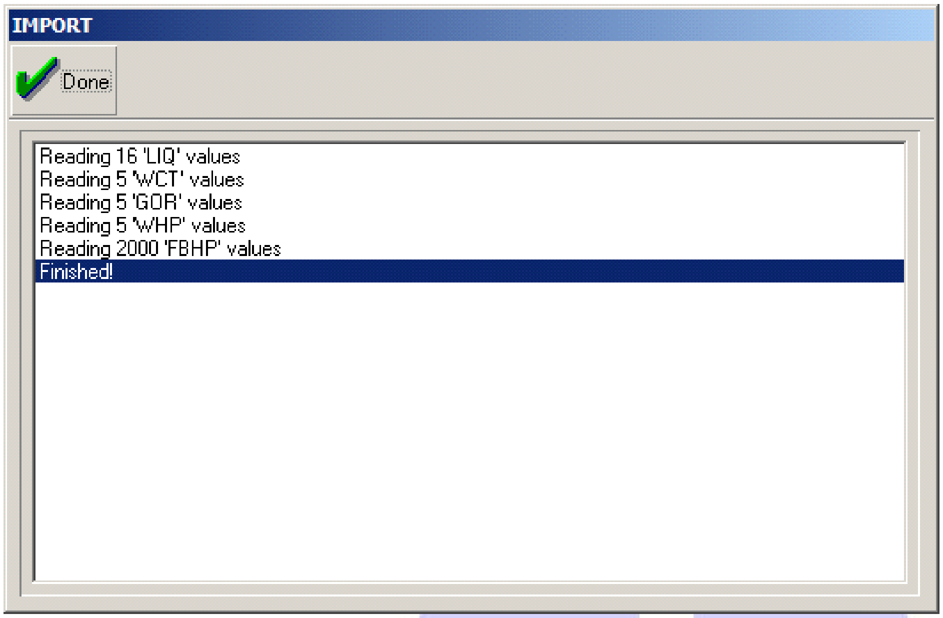
Gas Oil Ratio	*	scf/STB
Water Oil Ratio	*	

☐ Allow Recovery After Abandonment

The lift curves have been previously generated with **PROSPER** and can be imported using the “Edit” button shown above. Selecting this will prompt the following screen:

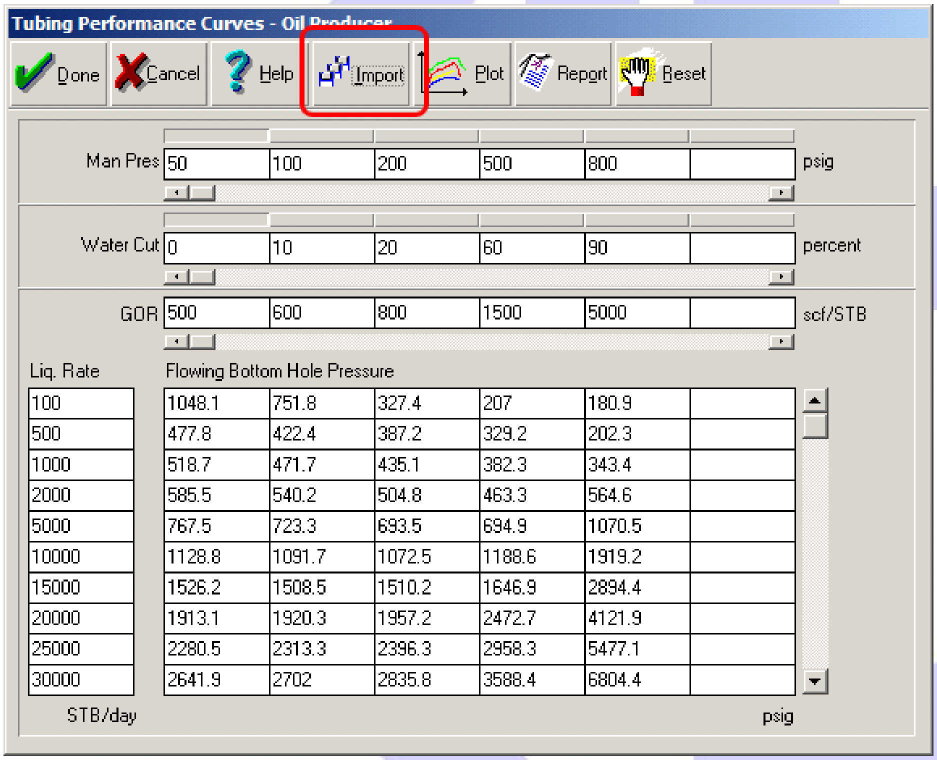

Tubing Performance Curves - Oil Producer
Done
Cancel
Help
Import
Plot
Report
Reset
Man Pres
psig
Water Cut
percent
GOR
scf/STB
Liq. Rate
Flowing Bottom Hole Pressure
STB/day
psig

The lift curves are stored as a *.tpd file in the Quick Start Guide samples folder and as soon as this imported, the following message will appear:


IMPORT
Done

Reading 16 'LIQ' values
Reading 5 'WCT' values
Reading 5 'GOR' values
Reading 5 'WHP' values
Reading 2000 'FBHP' values
Finished!

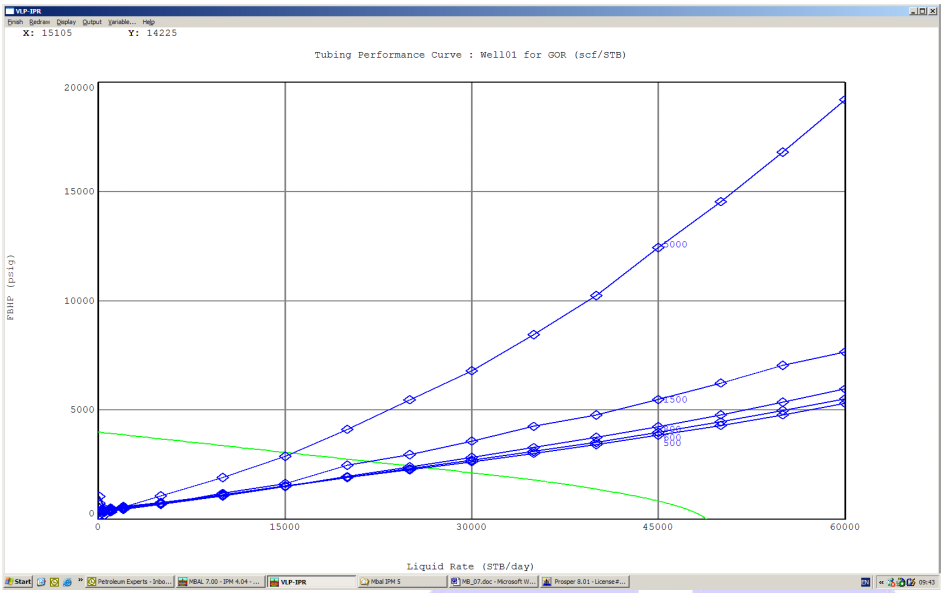
The VLP data can be seen in the screen below:


Tubing Performance Curves - Oil Producer
Done
Cancel
Help
Import
Plot
Report
Reset

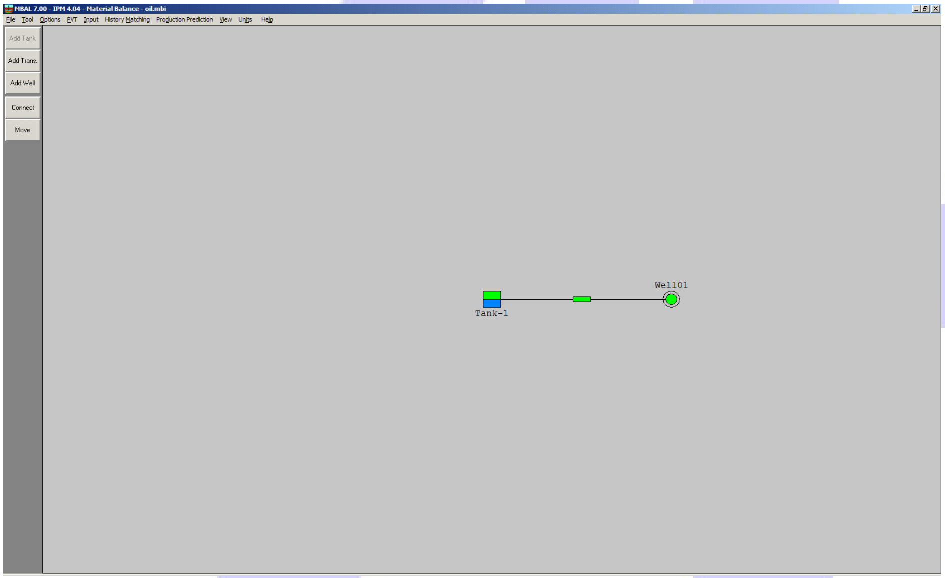
Man Pres	50	100	200	500	800	psig
Water Cut	0	10	20	60	90	percent
GOR	500	600	800	1500	5000	scf/STB

Liq. Rate	Flowing Bottom Hole Pressure				
100	1048.1	751.8	327.4	207	180.9
500	477.8	422.4	387.2	329.2	202.3
1000	518.7	471.7	435.1	382.3	343.4
2000	585.5	540.2	504.8	463.3	564.6
5000	767.5	723.3	693.5	694.9	1070.5
10000	1128.8	1091.7	1072.5	1188.6	1919.2
15000	1526.2	1508.5	1510.2	1646.9	2894.4
20000	1913.1	1920.3	1957.2	2472.7	4121.9
25000	2280.5	2313.3	2396.3	2958.3	5477.1
30000	2641.9	2702	2835.8	3588.4	6804.4
STB/day	psig				

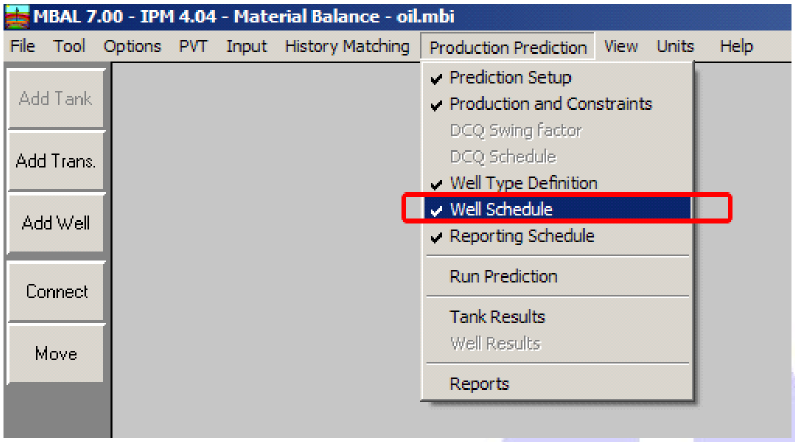
The data can also be plotted using the “Plot” button in the screen above:


VLP-IPR
Finish Redraw Display Output Variable... Help
X: 15105 Y: 14225
Tubing Performance Curve : Well01 for GOR (scf/STB)
FBHP (psig)
20000
15000
10000
5000
0
5000
1500
500
500
0
15000
30000
45000
60000
Liquid Rate (STB/day)

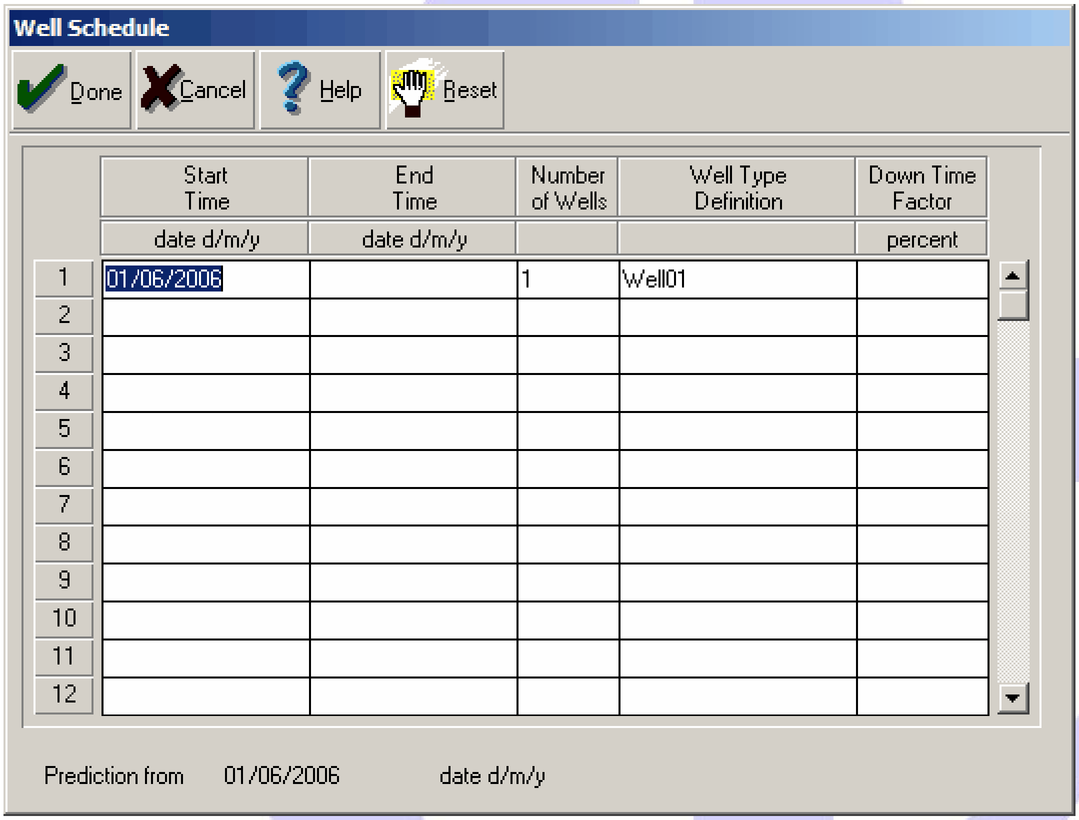
The well model is now completed and going back to the main screen of ***MBAL***, the well can be seen attached to the reservoir model:


MBAL 7.00 - IPM 4.04 - Material Balance - oil.mbi
File Tool Options PVT Input History Matching Production Prediction View Units Help
Add Tank
Add Trans.
Add Well
Connect
Move
Well01
Tank-1

The well now needs to be scheduled to be active. This is done from the “Well Schedule” option:


MBAL 7.00 - IPM 4.04 - Material Balance - oil.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Add Tank
Add Trans.
Add Well
Connect
Move
✓ Prediction Setup
✓ Production and Constraints
DCQ Swing factor
DCQ Schedule
✓ Well Type Definition
✓ Well Schedule
✓ Reporting Schedule
Run Prediction
Tank Results
Well Results
Reports

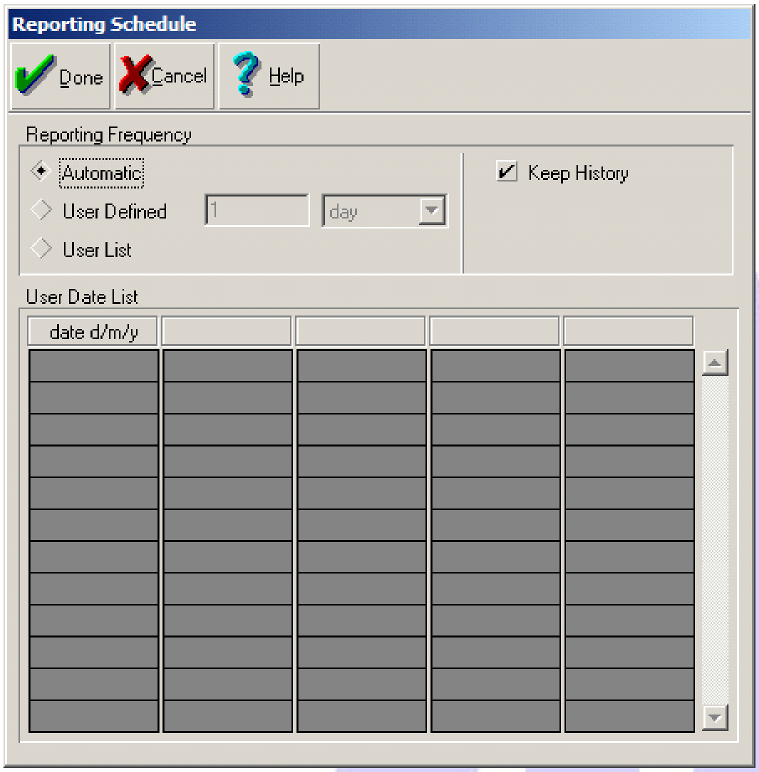
In this screen, the well opening and closing times can be defined; along with any possible downtime that this well will occur during the forecast period:


Well Schedule
Done
Cancel
Help
Reset

	Start Time	End Time	Number of Wells	Well Type Definition	Down Time Factor
	date d/m/y	date d/m/y			percent
1	01/06/2006		1	Well01	
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					

Prediction from 01/06/2006 date d/m/y

As soon as this is finished, the reporting schedule can be set (to automatic):


Reporting Schedule
Done
Cancel
Help
Reporting Frequency
User Date List
date d/m/y

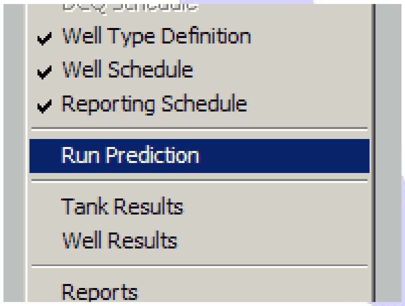
● Automatic
○ User Defined 1 day
○ User List

☑ Keep History

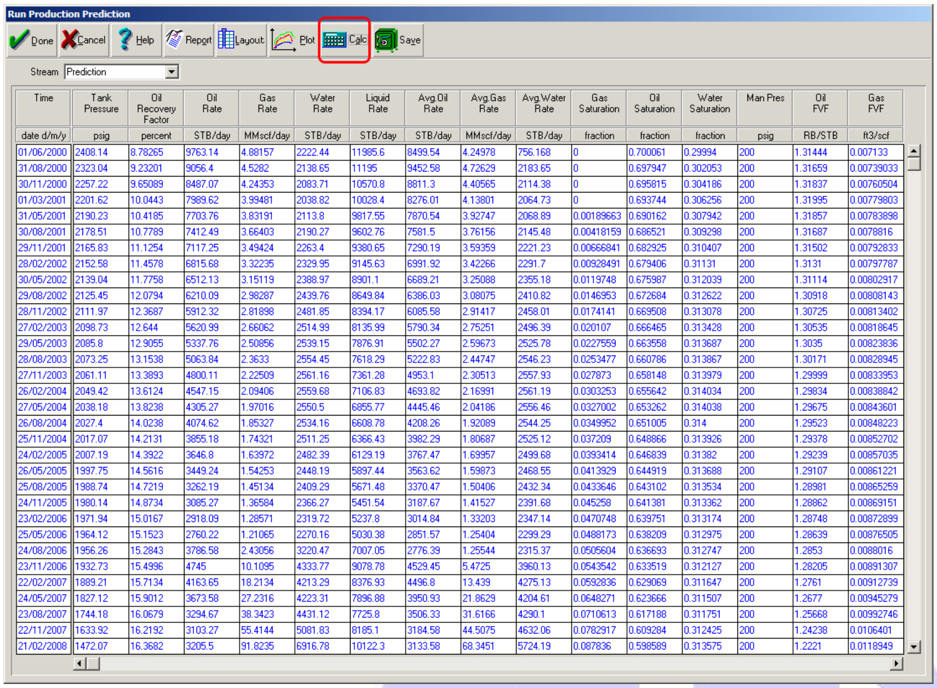
Please note that the "Keep History" button highlighted above can be checked if we would like **MBAL** to ignore the rel perms up to the first timestep of the prediction for the calculation of the reservoir pressure. This would mean that the initialisation of the reservoir up to the start of the prediction will be done with the actual rates of the history (for water and gas) as opposed to the ones calculated by the rel perms. This feature is particularly useful in cases where the fractional flow match can only reproduce a limited range of data as opposed to the full history production.

If mentioning this option then describe that the main impact is visual for results based on average rates.

The model is then ready for the forecast:


DCQ Schedule
Well Type Definition
Well Schedule
Reporting Schedule
Run Prediction
Tank Results
Well Results
Reports

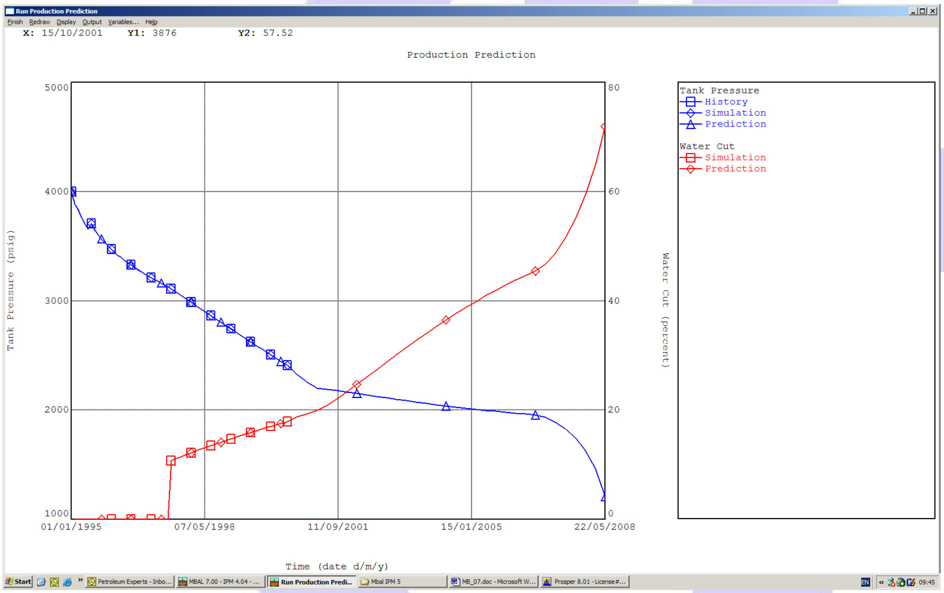
In the calculation screen, selecting “Calc” will generate the forecast:



Stream: Prediction

Time	Tank Pressure	Oil Recovery Factor	Oil Rate	Gas Rate	Water Rate	Liquid Rate	Avg.Oil Rate	Avg.Gas Rate	Avg.Water Rate	Gas Saturation	Oil Saturation	Water Saturation	Man Pres	Oil FVF	Gas FVF
date d/m/y	psig	percent	STB/day	MMscf/day	STB/day	STB/day	STB/day	MMscf/day	STB/day	fraction	fraction	fraction	psig	RB/STB	ft3/scf
01/06/2000	2408.14	8.78265	9763.14	4.88157	2222.44	11985.6	8499.54	4.24978	756.168	0	0.700061	0.29994	200	1.31444	0.007133
31/08/2000	2323.04	9.23201	9056.4	4.5282	2138.65	11195	9452.58	4.72629	2183.65	0	0.697947	0.302053	200	1.31659	0.00739033
30/11/2000	2257.22	9.65089	8487.07	4.24353	2083.71	10570.8	8811.3	4.40565	2114.38	0	0.695815	0.304186	200	1.31837	0.00760504
01/03/2001	2201.62	10.0443	7989.62	3.99481	2038.82	10028.4	8276.01	4.13801	2064.73	0	0.693744	0.306256	200	1.31995	0.00779803
31/05/2001	2190.23	10.4185	7703.76	3.83191	2113.8	9817.55	7870.54	3.92747	2068.89	0.00189663	0.690162	0.307942	200	1.31857	0.00783898
30/08/2001	2178.51	10.7789	7412.49	3.66403	2190.27	9602.76	7581.5	3.76156	2145.48	0.00418159	0.686521	0.309298	200	1.31687	0.0078816
29/11/2001	2165.83	11.1254	7117.25	3.49424	2263.4	9380.65	7290.19	3.59359	2221.23	0.00666841	0.682925	0.310407	200	1.31502	0.00792833
28/02/2002	2152.58	11.4578	6815.68	3.32235	2329.95	9145.63	6991.92	3.42266	2291.7	0.00928491	0.679406	0.31131	200	1.3131	0.00797787
30/05/2002	2139.04	11.7758	6512.13	3.15119	2388.97	8901.1	6689.21	3.25088	2355.18	0.0119748	0.675987	0.312039	200	1.31114	0.00802917
29/08/2002	2125.45	12.0794	6210.09	2.98287	2439.76	8649.84	6386.03	3.08075	2410.82	0.0146953	0.672684	0.312622	200	1.30918	0.00808143
28/11/2002	2111.97	12.3687	5912.32	2.81898	2481.85	8394.17	6085.58	2.91417	2458.01	0.0174141	0.669508	0.313078	200	1.30725	0.00813402
27/02/2003	2098.73	12.644	5620.99	2.66062	2514.99	8135.99	5790.34	2.75251	2496.39	0.020107	0.666465	0.313428	200	1.30535	0.00818645
29/05/2003	2085.8	12.9055	5337.76	2.50856	2539.15	7876.91	5502.27	2.59673	2525.78	0.0227559	0.663558	0.313687	200	1.3035	0.00823836
28/08/2003	2073.25	13.1538	5063.84	2.3633	2554.45	7618.29	5222.83	2.44747	2546.23	0.0253477	0.660786	0.313867	200	1.30171	0.00828945
27/11/2003	2061.11	13.3893	4800.11	2.22509	2561.16	7361.28	4953.1	2.30513	2557.93	0.027873	0.658148	0.313979	200	1.29999	0.00833953
26/02/2004	2049.42	13.6124	4547.15	2.09406	2559.68	7106.83	4693.82	2.16991	2561.19	0.0303253	0.655642	0.314034	200	1.29834	0.00838842
27/05/2004	2038.18	13.8238	4305.27	1.97016	2550.5	6855.77	4445.46	2.04186	2556.46	0.0327002	0.653262	0.314038	200	1.29675	0.00843601
26/08/2004	2027.4	14.0238	4074.62	1.85327	2534.16	6608.78	4208.26	1.92089	2544.25	0.0349952	0.651005	0.314	200	1.29523	0.00848223
25/11/2004	2017.07	14.2131	3855.18	1.74321	2511.25	6366.43	3982.29	1.80687	2525.12	0.037209	0.648866	0.313926	200	1.29378	0.00852702
24/02/2005	2007.19	14.3922	3646.8	1.63972	2482.39	6129.19	3767.47	1.69957	2499.68	0.0393414	0.646839	0.31382	200	1.29239	0.00857035
26/05/2005	1997.75	14.5616	3449.24	1.54253	2448.19	5897.44	3563.62	1.59873	2468.55	0.0413929	0.644919	0.313688	200	1.29107	0.00861221
25/08/2005	1988.74	14.7219	3262.19	1.45134	2409.29	5671.48	3370.47	1.50406	2432.34	0.0433646	0.643102	0.313534	200	1.28981	0.00865259
24/11/2005	1980.14	14.8734	3085.27	1.36584	2366.27	5451.54	3187.67	1.41527	2391.68	0.045258	0.641381	0.313362	200	1.28862	0.00869151
23/02/2006	1971.94	15.0167	2918.09	1.28571	2319.72	5237.8	3014.84	1.33203	2347.14	0.0470748	0.639751	0.313174	200	1.28748	0.00872899
25/05/2006	1964.12	15.1523	2760.22	1.21065	2270.16	5030.38	2851.57	1.25404	2299.29	0.0488173	0.638209	0.312975	200	1.28639	0.00876505
24/08/2006	1956.26	15.2843	3786.58	2.43056	3220.47	7007.05	2776.39	1.25544	2315.37	0.0505604	0.636693	0.312747	200	1.2853	0.0088016
23/11/2006	1932.73	15.4996	4745	10.1095	4333.77	9078.78	4529.45	5.4725	3960.13	0.0543542	0.633519	0.312127	200	1.28205	0.00891307
22/02/2007	1889.21	15.7134	4163.65	18.2134	4213.29	8376.93	4496.8	13.439	4275.13	0.0592836	0.629069	0.311647	200	1.2761	0.00912739
24/05/2007	1827.12	15.9012	3673.58	27.2316	4223.31	7896.88	3950.93	21.8629	4204.61	0.0648271	0.623666	0.311507	200	1.2677	0.00945279
23/08/2007	1744.18	16.0679	3294.67	38.3423	4431.12	7725.8	3506.33	31.6166	4290.1	0.0710613	0.617188	0.311751	200	1.25668	0.00992746
22/11/2007	1633.92	16.2192	3103.27	55.4144	5081.83	8185.1	3184.58	44.5075	4632.06	0.0782917	0.609284	0.312425	200	1.24238	0.0106401
21/02/2008	1472.07	16.3682	3205.5	91.8235	6916.78	10122.3	3133.58	68.3451	5724.19	0.087836	0.598589	0.313575	200	1.2221	0.0118949

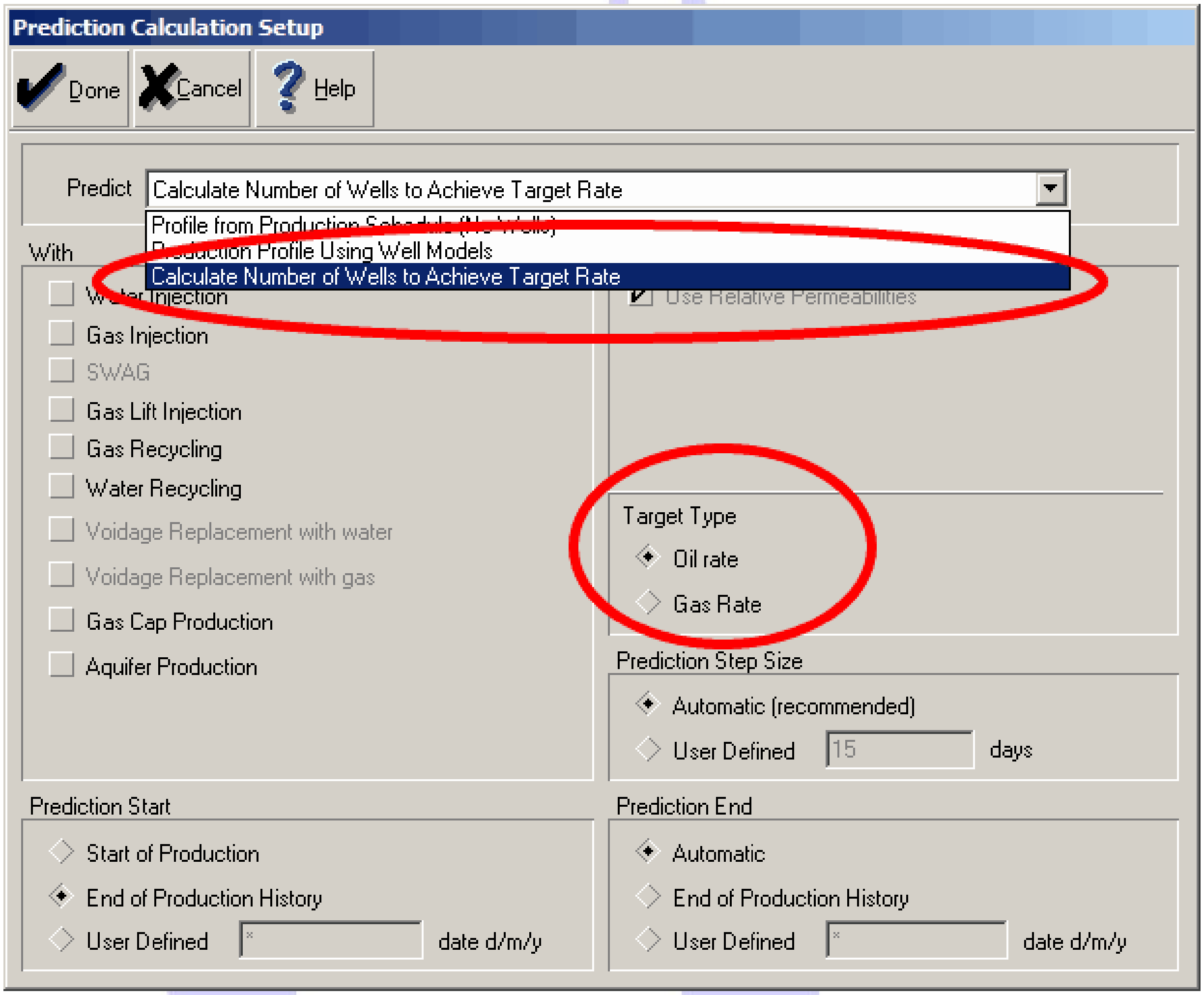
Of course, the results can be plotted as in previous cases:



This concludes the example. The completed **MBAL** file along with the constituting files can be found in the **MBAL** samples directory, under the Quick Start guide folder.

3.1.4.5 Predicting number of wells to achieve target rate

This was a new addition to **IPM** 6 as a forecasting mode:



Predict: Calculate Number of Wells to Achieve Target Rate

- Profile from Production Schedule (No Wells)
- Production Profile Using Well Models
- Calculate Number of Wells to Achieve Target Rate

With

☐ Water Injection
☐ Gas Injection
☐ SWAG
☐ Gas Lift Injection
☐ Gas Recycling
☐ Water Recycling
☐ Voidage Replacement with water
☐ Voidage Replacement with gas
☐ Gas Cap Production
☐ Aquifer Production

☑ Use Relative Permeabilities

Target Type
● Oil rate
○ Gas Rate

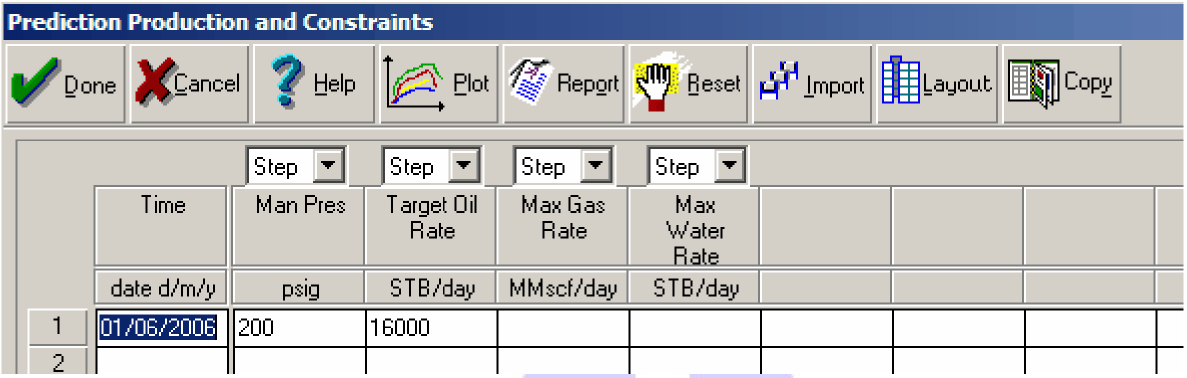
Prediction Step Size
● Automatic (recommended)
○ User Defined 15 days

Prediction Start
○ Start of Production
● End of Production History
○ User Defined date d/m/y

Prediction End
● Automatic
○ End of Production History
○ User Defined date d/m/y

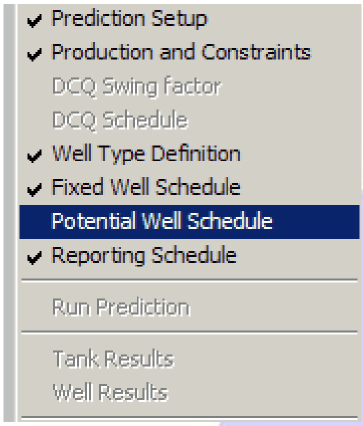
As soon as this option is selected, the program can use a particular well type and add as many wells of this type as needed to achieve a particular target (if of course the target is physically achievable).

Going through the options from top to bottom, in the 'Production and Constraints' tab, we can enter the target rates:

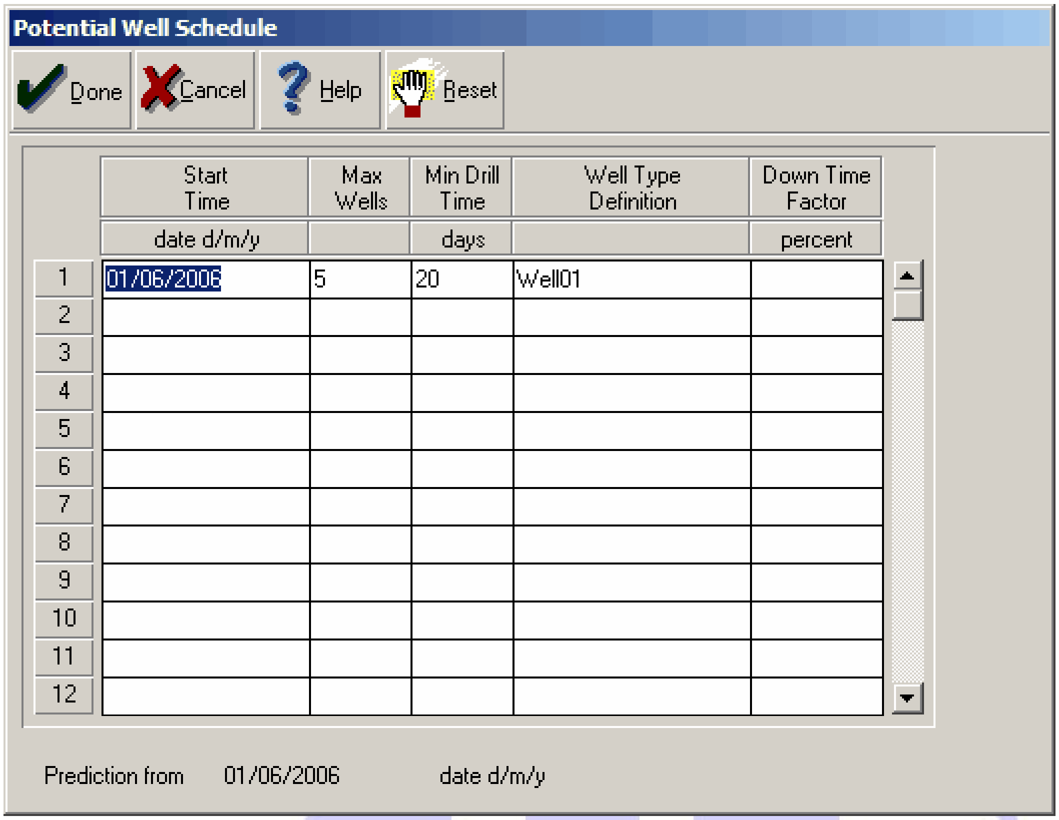

Prediction Production and Constraints
Done
Cancel
Help
Plot
Report
Reset
Import
Layout
Copy

		Step	Step	Step	Step				
	Time	Man Pres	Target Oil Rate	Max Gas Rate	Max Water Rate				
	date d/m/y	psig	STB/day	MMscf/day	STB/day				
1	01/06/2006	200	16000						
2									

In the 'Prediction' menu, a new option will appear relating the potential well schedule.


✓ Prediction Setup
✓ Production and Constraints
DCQ Swing factor
DCQ Schedule
✓ Well Type Definition
✓ Fixed Well Schedule
Potential Well Schedule
✓ Reporting Schedule
Run Prediction
Tank Results
Well Results

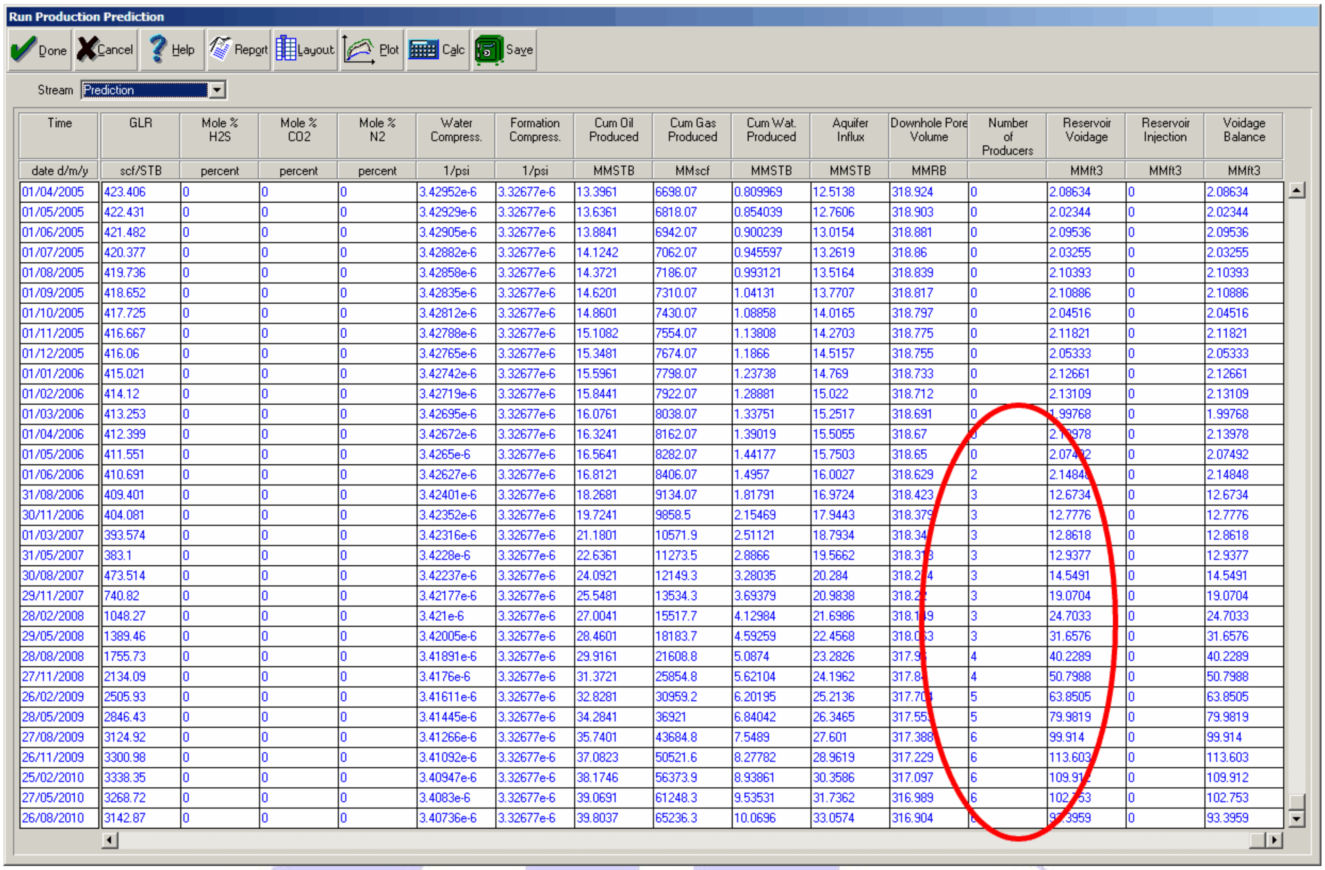
This screen will allow the user to enter how many wells are available for **MBAL** to select and of which type:


Potential Well Schedule
Done
Cancel
Help
Reset

	Start Time	Max Wells	Min Drill Time	Well Type Definition	Down Time Factor
	date d/m/y		days		percent
1	01/06/2006	5	20	Well01	
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					

Prediction from 01/06/2006 date d/m/y

Now we can run the forecast and scrolling to the right of the results screen, the number of wells chosen is shown by **MBAL**:



Stream: Prediction

Time	GLR	Mole % H2S	Mole % CO2	Mole % N2	Water Compress.	Formation Compress.	Cum Oil Produced	Cum Gas Produced	Cum Wat. Produced	Aquifer Influx	Downhole Pore Volume	Number of Producers	Reservoir Voidage	Reservoir Injection	Voidage Balance
date d/m/y	scf/STB	percent	percent	percent	1/psi	1/psi	MMSTB	MMscf	MMSTB	MMSTB	MMRB		MMft3	MMft3	MMft3
01/04/2005	423.406	0	0	0	3.42952e-6	3.32677e-6	13.3961	6698.07	0.809969	12.5138	318.924	0	2.08634	0	2.08634
01/05/2005	422.431	0	0	0	3.42929e-6	3.32677e-6	13.6361	6818.07	0.854039	12.7606	318.903	0	2.02344	0	2.02344
01/06/2005	421.482	0	0	0	3.42905e-6	3.32677e-6	13.8841	6942.07	0.900239	13.0154	318.881	0	2.09536	0	2.09536
01/07/2005	420.377	0	0	0	3.42882e-6	3.32677e-6	14.1242	7062.07	0.945597	13.2619	318.86	0	2.03255	0	2.03255
01/08/2005	419.736	0	0	0	3.42858e-6	3.32677e-6	14.3721	7186.07	0.993121	13.5164	318.839	0	2.10393	0	2.10393
01/09/2005	418.652	0	0	0	3.42835e-6	3.32677e-6	14.6201	7310.07	1.04131	13.7707	318.817	0	2.10886	0	2.10886
01/10/2005	417.725	0	0	0	3.42812e-6	3.32677e-6	14.8601	7430.07	1.08858	14.0165	318.797	0	2.04516	0	2.04516
01/11/2005	416.667	0	0	0	3.42788e-6	3.32677e-6	15.1082	7554.07	1.13808	14.2703	318.775	0	2.11821	0	2.11821
01/12/2005	416.06	0	0	0	3.42765e-6	3.32677e-6	15.3481	7674.07	1.1866	14.5157	318.755	0	2.05333	0	2.05333
01/01/2006	415.021	0	0	0	3.42742e-6	3.32677e-6	15.5961	7798.07	1.23738	14.769	318.733	0	2.12661	0	2.12661
01/02/2006	414.12	0	0	0	3.42719e-6	3.32677e-6	15.8441	7922.07	1.28881	15.022	318.712	0	2.13109	0	2.13109
01/03/2006	413.253	0	0	0	3.42695e-6	3.32677e-6	16.0761	8038.07	1.33751	15.2517	318.691	0	1.99768	0	1.99768
01/04/2006	412.399	0	0	0	3.42672e-6	3.32677e-6	16.3241	8162.07	1.39019	15.5055	318.67	0	[illegible]	0	2.13978
01/05/2006	411.551	0	0	0	3.4265e-6	3.32677e-6	16.5641	8282.07	1.44177	15.7503	318.65	0	[illegible]	0	2.07492
01/06/2006	410.691	0	0	0	3.42627e-6	3.32677e-6	16.8121	8406.07	1.4957	16.0027	318.629	2	[illegible]	0	2.14848
31/08/2006	409.401	0	0	0	3.42401e-6	3.32677e-6	18.2681	9134.07	1.81791	16.9724	318.423	3	12.6734	0	12.6734
30/11/2006	404.081	0	0	0	3.42352e-6	3.32677e-6	19.7241	9858.5	2.15469	17.9443	318.379	3	12.7776	0	12.7776
01/03/2007	393.574	0	0	0	3.42316e-6	3.32677e-6	21.1801	10571.9	2.51121	18.7934	[illegible]	3	12.8618	0	12.8618
31/05/2007	383.1	0	0	0	3.4228e-6	3.32677e-6	22.6361	11273.5	2.8866	19.5662	[illegible]	3	12.9377	0	12.9377
30/08/2007	473.514	0	0	0	3.42237e-6	3.32677e-6	24.0921	12149.3	3.28035	20.284	[illegible]	3	14.5491	0	14.5491
29/11/2007	740.82	0	0	0	3.42177e-6	3.32677e-6	25.5481	13534.3	3.69379	20.9838	[illegible]	3	19.0704	0	19.0704
28/02/2008	1048.27	0	0	0	3.421e-6	3.32677e-6	27.0041	15517.7	4.12984	21.6986	[illegible]	3	24.7033	0	24.7033
29/05/2008	1389.46	0	0	0	3.42005e-6	3.32677e-6	28.4601	18183.7	4.59259	22.4568	[illegible]	3	31.6576	0	31.6576
28/08/2008	1755.73	0	0	0	3.41891e-6	3.32677e-6	29.9161	21608.8	5.0874	23.2826	[illegible]	4	40.2289	0	40.2289
27/11/2008	2134.09	0	0	0	3.4176e-6	3.32677e-6	31.3721	25854.8	5.62104	24.1962	[illegible]	4	50.7988	0	50.7988
26/02/2009	2505.93	0	0	0	3.41611e-6	3.32677e-6	32.8281	30959.2	6.20195	25.2136	[illegible]	5	63.8505	0	63.8505
28/05/2009	2846.43	0	0	0	3.41445e-6	3.32677e-6	34.2841	36921	6.84042	26.3465	[illegible]	5	79.9819	0	79.9819
27/08/2009	3124.92	0	0	0	3.41266e-6	3.32677e-6	35.7401	43684.8	7.5489	27.601	317.388	6	99.914	0	99.914
26/11/2009	3300.98	0	0	0	3.41092e-6	3.32677e-6	37.0823	50521.6	8.27782	28.9619	317.229	6	113.603	0	113.603
25/02/2010	3338.35	0	0	0	3.40947e-6	3.32677e-6	38.1746	56373.9	8.93861	30.3586	317.097	6	[illegible]	0	109.912
27/05/2010	3268.72	0	0	0	3.4083e-6	3.32677e-6	39.0691	61248.3	9.53531	31.7362	316.989	6	[illegible]	0	102.753
26/08/2010	3142.87	0	0	0	3.40736e-6	3.32677e-6	39.8037	65236.3	10.0696	33.0574	316.904	[illegible]	[illegible]	0	93.3959

The rate is kept at 16000 for as long as possible. It is worth noting that the fixed wells will be present in the forecast from the beginning and will not form part of the selected wells to be drilled. If the existing wells can satisfy the production and also need to be choked back, then the program will keep them producing, until such a time as the production will drop below the target when the existing wells are fully open. At this point only will **MBAL** start adding new wells from the available potential well schedule.

3.2 Water Drive Oil Reservoir

Objectives

A reservoir with: an initial pressure of 2740psi, a GOR of 650 scf/STB and oil gravity of 40 API has been producing for ten years.
Material balance will be applied to the ten year historical data to establish: the STOIIP, whether there has been aquifer support and then define the aquifer parameters.

Having defined the reservoir and aquifer parameters, a comparison between the historical data and the calculated values can be carried out to ensure that the measured data is reproducible.

Learning Summary

The objectives of this example are to allow the user to familiarise themselves with the available functions and necessary methodology to ensure an accurate tank model.
The following will be covered:

- The definition of the modelling option in use.
- The input of PVT and any matching to lab data to use the most appropriate correlation
- The input of tank parameters
- Evaluation of aquifer presence and input of aquifer information
- Performing a history match
- Regressing on the initially defined parameters to ensure that material balance reproduces the real measured data

The files for this example and the final tank model can be found in the MBAL archive file format:

~\Samples\MBAL\Oil_tst.mbi

Executive Summary

The steps in this example will cover the following:

- Setting modelling options
- Entering PVT properties and performing a correlation match
- Entering reservoir and aquifer properties
- Entering production history data
- Performing a history match
- Using regression to improve the match

This example is based on data from *Fundamentals of Reservoir Engineering* by L.P. Dake (Elsevier, 1978), Chapter 9.

Data Available

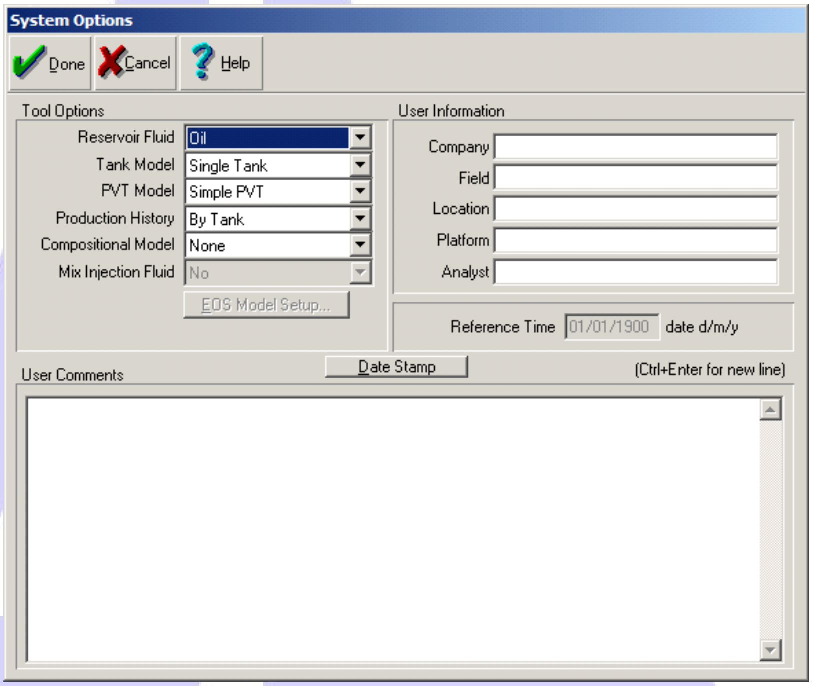
- Initial reservoir pressure: 2740psig
- Initial reservoir temperature: 115°F
- Initial oil in place: 300STB

3.2.1 Starting the Model

Clearing any previous calculations by selecting **FILE|NEW**; the detail concerning the type of model to be defined can be entered.

Select **TOOL|MATERIAL BALANCE**, and then click **OPTIONS** from the main menu.

The following selections can be made:

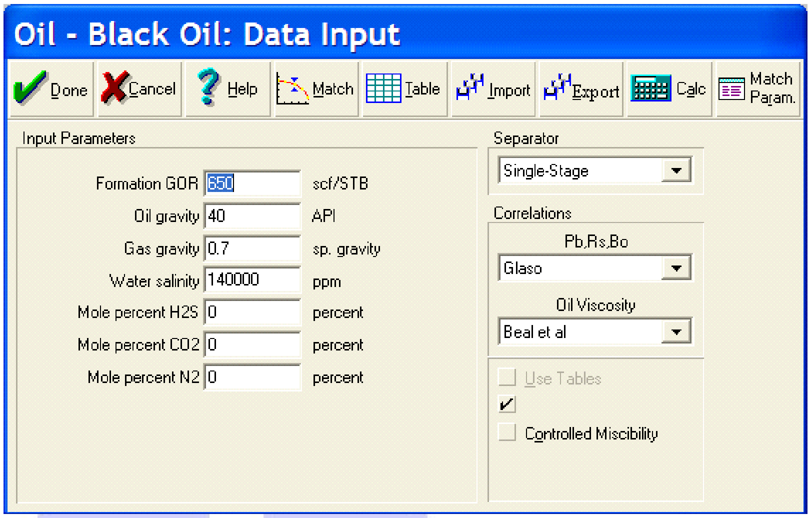

System Options
Done
Cancel
Help
Tool Options
User Information
Company
Field
Location
Platform
Analyst
EOS Model Setup...
User Comments
Date Stamp
(Ctrl+Enter for new line)

Reservoir Fluid: Oil
Tank Model: Single Tank
PVT Model: Simple PVT
Production History: By Tank
Compositional Model: None
Mix Injection Fluid: No
Reference Time: 01/01/1900 date d/m/y

Click **DONE** to return to the main menu.

3.2.2 PVT Menu

Select **PVT|FLUID PROPERTIES** and enter the following PVT data:


Oil - Black Oil: Data Input
Done
Cancel
Help
Match
Table
Import
Export
Calc
Match Param.

Input Parameters

Formation GOR 650 scf/STB
Oil gravity 40 API
Gas gravity 0.7 sp. gravity
Water salinity 140000 ppm
Mole percent H2S 0 percent
Mole percent CO2 0 percent
Mole percent N2 0 percent

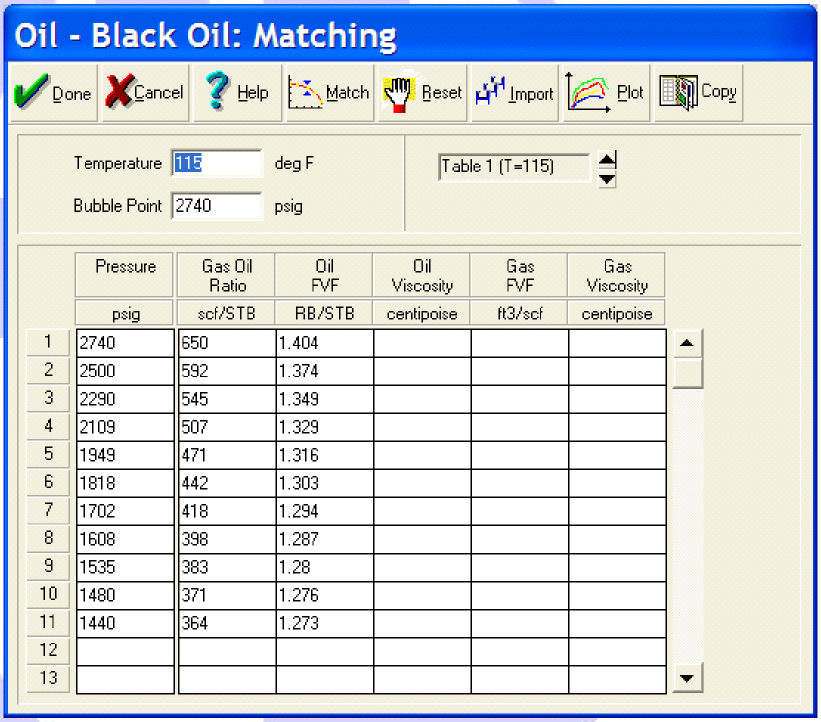
Separator
Single-Stage

Correlations
Pb,Rs,Bo
Glaso
Oil Viscosity
Beal et al

☐ Use Tables
☑
☐ Controlled Miscibility

Having entered the PVT data, the most appropriate correlations to model the fluid behaviour are still yo be established.

So the PVT correlations will now be matched to lab PVT data (**This data is taken from page 320 of Dake**).

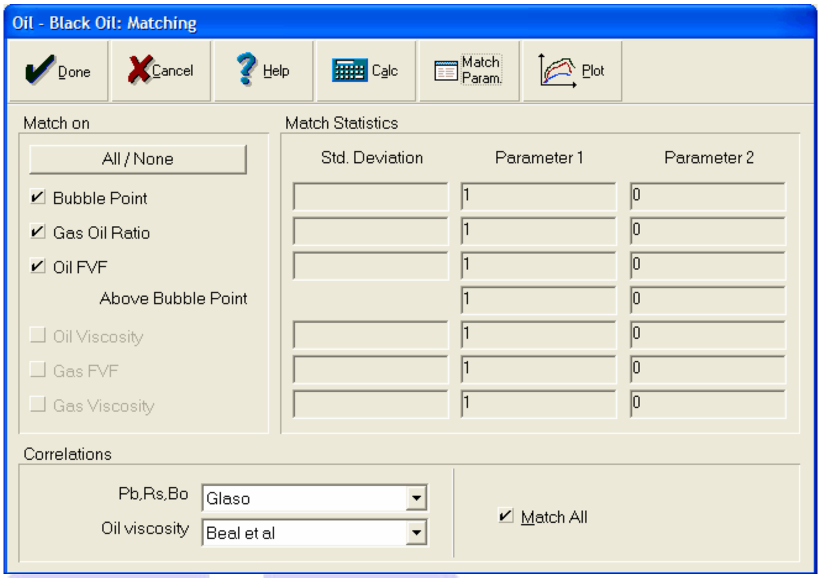

Oil - Black Oil: Matching
Done
Cancel
Help
Match
Reset
Import
Plot
Copy

Temperature 115 deg F
Bubble Point 2740 psig

Table 1 (T=115)

	Pressure	Gas Oil Ratio	Oil FVF	Oil Viscosity	Gas FVF	Gas Viscosity
	psig	scf/STB	RB/STB	centipoise	ft3/scf	centipoise
1	2740	650	1.404			
2	2500	592	1.374			
3	2290	545	1.349			
4	2109	507	1.329			
5	1949	471	1.316			
6	1818	442	1.303			
7	1702	418	1.294			
8	1608	398	1.287			
9	1535	383	1.28			
10	1480	371	1.276			
11	1440	364	1.273			
12						
13						

As soon as the data has been entered, the “Match Button” will need to be selected, prompting the regression screen to appear:


Oil - Black Oil: Matching
Done
Cancel
Help
Calc
Match Param.
Plot
All / None

Match on

- ☑ Bubble Point
- ☑ Gas Oil Ratio
- ☑ Oil FVF
- Above Bubble Point
- ☐ Oil Viscosity
- ☐ Gas FVF
- ☐ Gas Viscosity

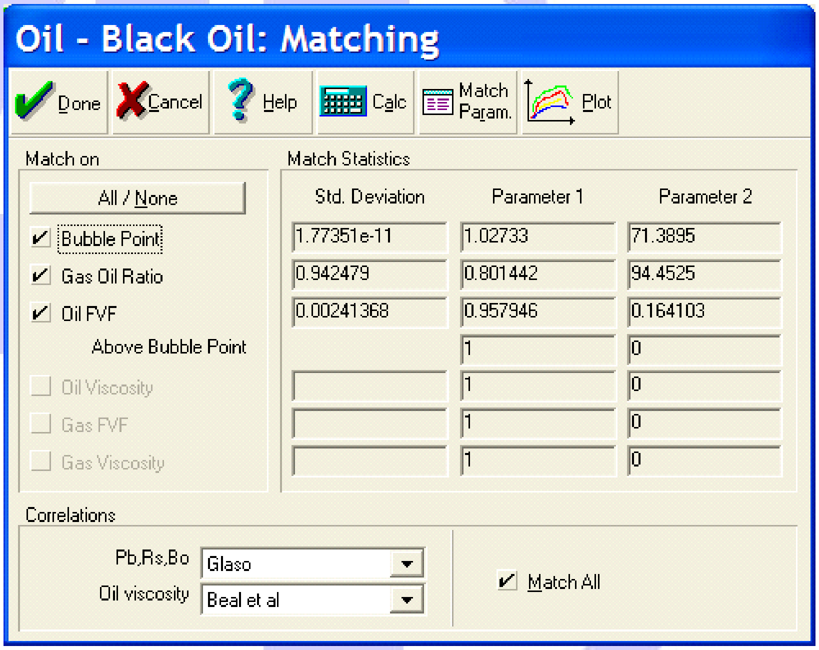
Match Statistics

	Std. Deviation	Parameter 1	Parameter 2
Bubble Point		1	0
Gas Oil Ratio		1	0
Oil FVF		1	0
Above Bubble Point		1	0
Oil Viscosity		1	0
Gas FVF		1	0
Gas Viscosity		1	0

Correlations

Pb,Rs,Bo: Glaso
Oil viscosity: Beal et al
☑ Match All

Click on the 'CALC' button to perform the regression. As soon as the calculations are finished, the “Match Parameters” screen will allow selection of the correlation that best matches the data:


Oil - Black Oil: Matching
Done
Cancel
Help
Calc
Match Param.
Plot
All / None

Match on

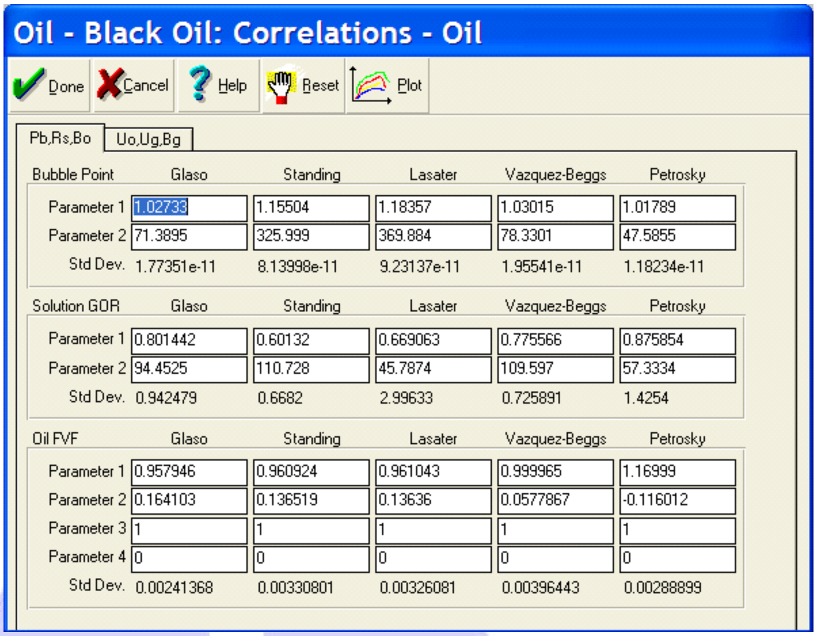
- ☑ Bubble Point
- ☑ Gas Oil Ratio
- ☑ Oil FVF
- Above Bubble Point
- ☐ Oil Viscosity
- ☐ Gas FVF
- ☐ Gas Viscosity

Match Statistics

	Std. Deviation	Parameter 1	Parameter 2
Bubble Point	1.77351e-11	1.02733	71.3895
Gas Oil Ratio	0.942479	0.801442	94.4525
Oil FVF	0.00241368	0.957946	0.164103
Above Bubble Point		1	0
Oil Viscosity		1	0
Gas FVF		1	0
Gas Viscosity		1	0

Correlations

Pb,Rs,Bo: Glaso
Oil viscosity: Beal et al
☑ Match All



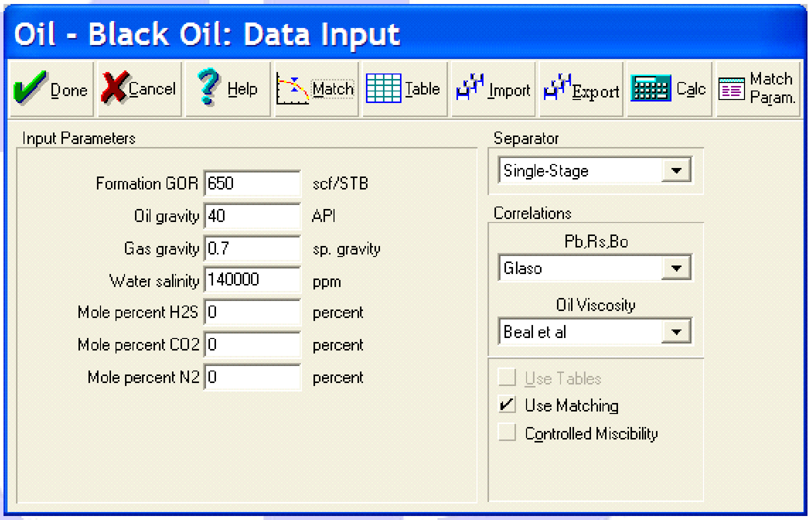
Bubble Point	Glaso	Standing	Lasater	Vazquez-Beggs	Petrosky
Parameter 1	1.02733	1.15504	1.18357	1.03015	1.01789
Parameter 2	71.3895	325.999	369.884	78.3301	47.5855
Std Dev.	1.77351e-11	8.13998e-11	9.23137e-11	1.95541e-11	1.18234e-11

Solution GOR	Glaso	Standing	Lasater	Vazquez-Beggs	Petrosky
Parameter 1	0.801442	0.60132	0.669063	0.775566	0.875854
Parameter 2	94.4525	110.728	45.7874	109.597	57.3334
Std Dev.	0.942479	0.6682	2.99633	0.725891	1.4254

Oil FVF	Glaso	Standing	Lasater	Vazquez-Beggs	Petrosky
Parameter 1	0.957946	0.960924	0.961043	0.999965	1.16999
Parameter 2	0.164103	0.136519	0.13636	0.0577867	-0.116012
Parameter 3	1	1	1	1	1
Parameter 4	0	0	0	0	0
Std Dev.	0.00241368	0.00330801	0.00326081	0.00396443	0.00288899

When looking at parameter 1, for: Bubble Point, Solution GOR and Oil FVF, the most appropriate correlation (the one requiring the least adjustment/matching) will have a value close to 1. From this, 'Glaso' (the default correlation) is deemed best and therefore does not need to be changed in the main PVT screen.

The viscosity correlation is also kept to the default of 'Beal et al.' due to the lack of matching data for it.



Input Parameters

Formation GOR 650 scf/STB
Oil gravity 40 API
Gas gravity 0.7 sp. gravity
Water salinity 140000 ppm
Mole percent H2S 0 percent
Mole percent CO2 0 percent
Mole percent N2 0 percent

Separator
Single-Stage

Correlations
Pb,Rs,Bo
Glaso
Oil Viscosity
Beal et al

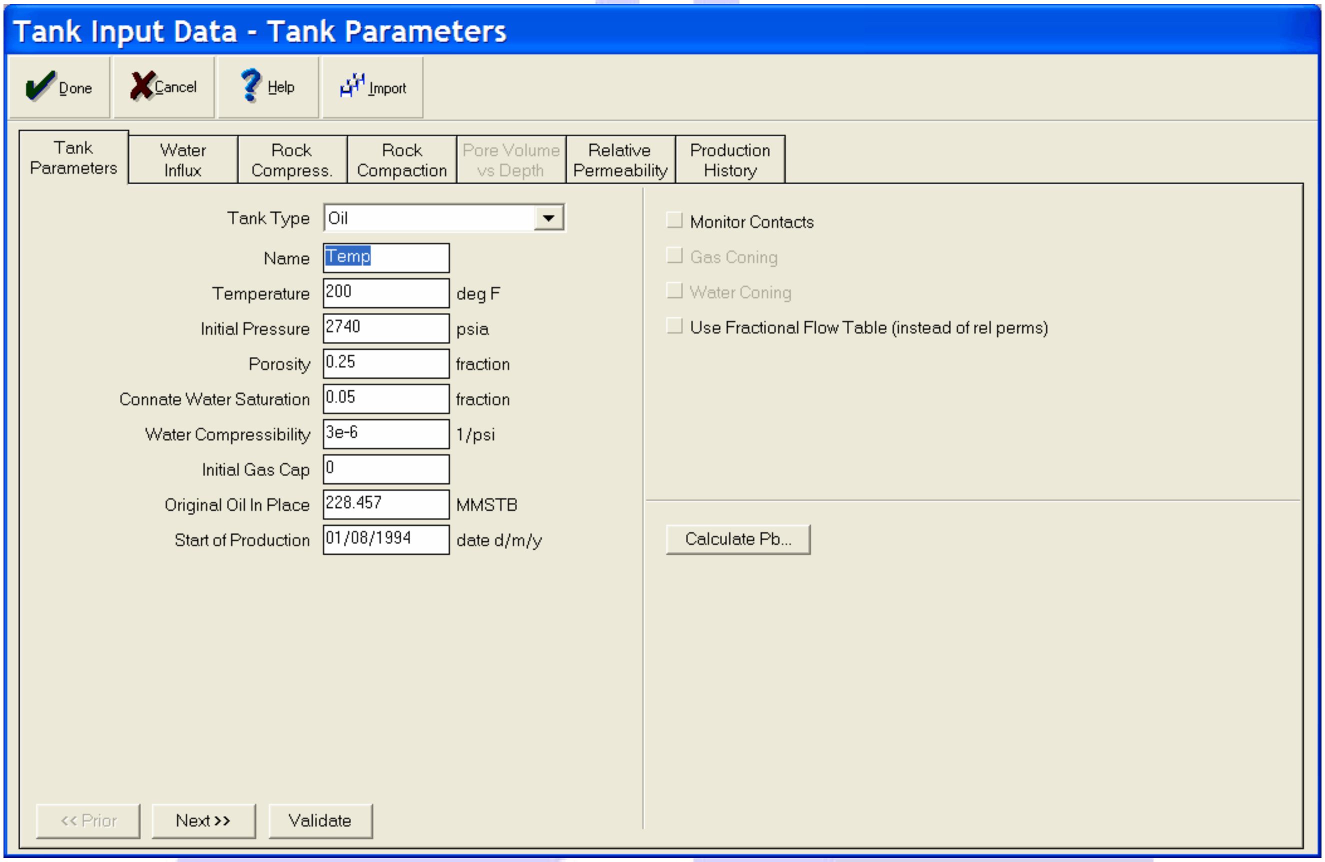
☐ Use Tables
☑ Use Matching
☐ Controlled Miscibility

Having completed the PVT section, the next section will describe how the reservoir data is entered.

3.2.3 Reservoir Input

Reservoir Input

The data used in this section is shown in Dake, page 317.


Tank Input Data - Tank Parameters
Done
Cancel
Help
Import
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
Calculate Pb...
<< Prior
Next >>
Validate

Tank Type	Oil	
Name	Temp	
Temperature	200	deg F
Initial Pressure	2740	psia
Porosity	0.25	fraction
Connate Water Saturation	0.05	fraction
Water Compressibility	3e-6	1/psi
Initial Gas Cap	0	
Original Oil In Place	228.457	MMSTB
Start of Production	01/08/1994	date d/m/y

☐ Monitor Contacts
☐ Gas Coning
☐ Water Coning
☐ Use Fractional Flow Table (instead of rel perms)

It should be noted some of the data is not available in the book, such as the reservoir temperature.
The PVT data is given as tables with no temperature defined so a value of 115 deg F is in use for this example.

3.2.4 Rock Properties

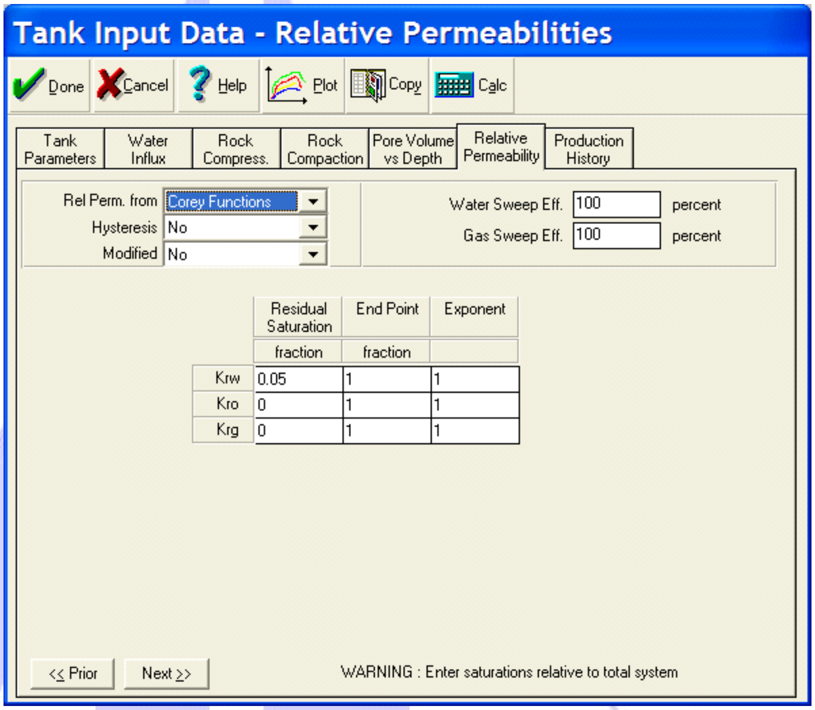
Next click on the **Rock Properties** tab. Select the User Specified button and enter the following:

Rock Compressibility	4.0e-06

This value is specified in the exercise, page 317.

3.2.5 Relative Permeability

The next step is to select the **Relative Permeability** tab:


Tank Input Data - Relative Permeabilities
Done
Cancel
Help
Plot
Copy
Calc
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
<< Prior
Next >>

Rel Perm. from: Corey Functions
Hysteresis: No
Modified: No
Water Sweep Eff. 100 percent
Gas Sweep Eff. 100 percent

	Residual Saturation	End Point	Exponent
	fraction	fraction	
Krw	0.05	1	1
Kro	0	1	1
Krg	0	1	1

WARNING : Enter saturations relative to total system

In Dake's example, no rel perms are given for the fluid so in this case, straight line rel perms have been used for simplicity. This allows a directly linear relationship between the different fluid viscosities and their ability to travel across the formation to be accounted for when running prediction calculations.
The Relative Permeability entry impacts on the connate saturations only when carrying out the history matching system.

3.2.6 Production History

The next task is to set up the production history. Click on the **Production History** tab. Enter the following production data:

Time d/m/y	Reservoir Pressure Psig	Cum Oil Produced MMSTB	Cum Gas Produced MMscf
01/08/1994	2740	0	0
01/08/1995	2500	7.88	5988.8
01/08/1996	2290	18.42	15564.9
01/08/1997	2109	29.15	26818

01/08/1998	1949	40.69	39672.8
01/08/1999	1818	50.14	51393.5
01/08/2000	1702	58.42	62217.3
01/08/2001	1608	65.39	71602.1
01/08/2002	1535	70.74	79228.8
01/08/2003	1480	74.54	85348.3
01/08/2004	1440	77.43	89818.8

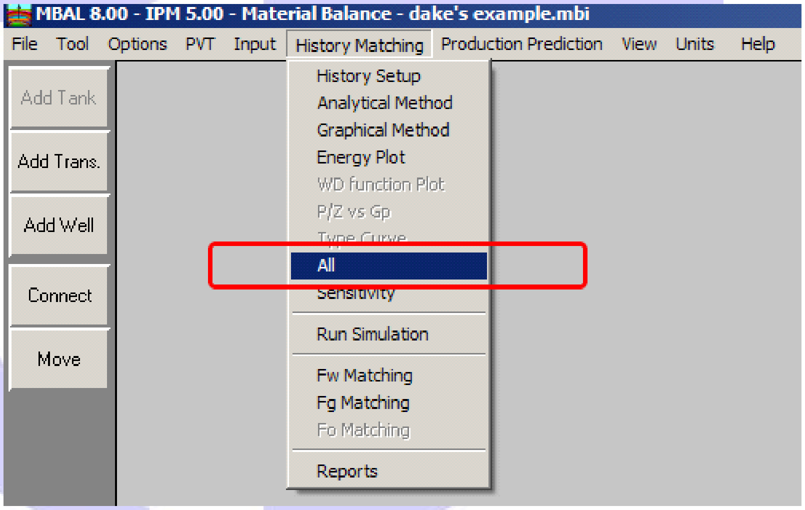
This data is taken from page 320 of Dake, table 9.3

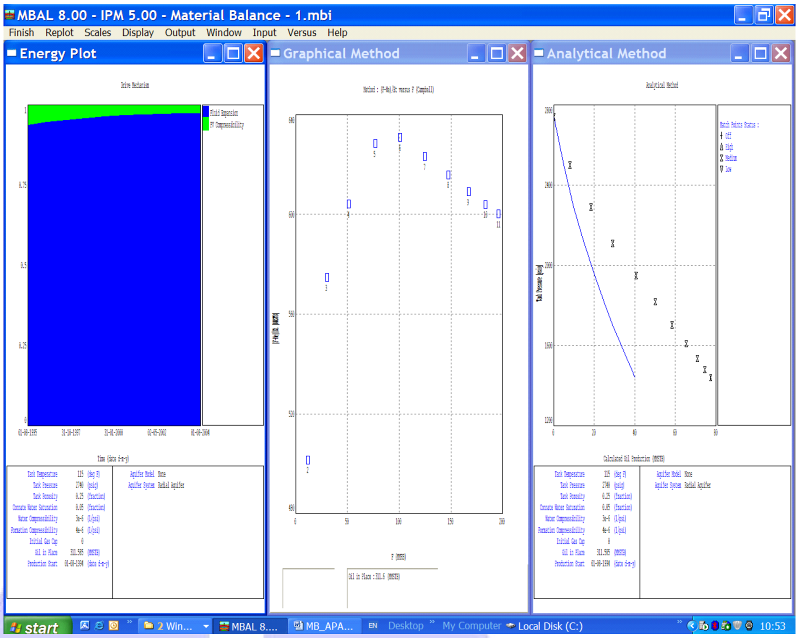
3.2.7 History Matching

History matching allows for the evaluation of the driving forces within the system which have contributed to the historical production.

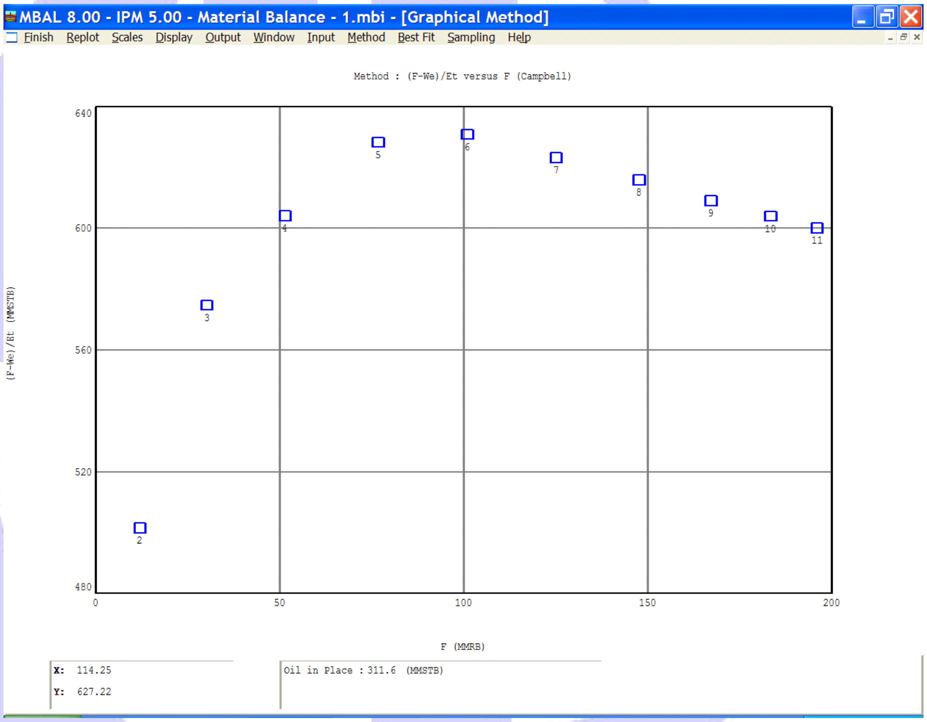
This section will illustrate the methodology for carrying out the matching process and comparing the results obtained using a number of different methods.
It should be noted that the initial set of reservoir data entered in the **Input** section is used only as a starting point for the history matching.

The aquifer was initially disallowed. This will enable us to assess whether an aquifer is present or not. Click **History Matching|All** and 3 tiled windows showing the available methods will be displayed.


MBAL 8.00 - IPM 5.00 - Material Balance - dake's example.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Add Tank
Add Trans.
Add Well
Connect
Move
History Setup
Analytical Method
Graphical Method
Energy Plot
WD function Plot
P/Z vs Gp
Type Curve
All
Sensitivity
Run Simulation
Fw Matching
Fg Matching
Fo Matching
Reports


MBAL 8.00 - IPM 5.00 - Material Balance - 1.mbi
Finish Replot Scales Display Output Window Input Versus Help
Energy Plot
Graphical Method
Analytical Method
start
2 Win...
MBAL 8....
MB_APA...
Desktop
My Computer
Local Disk (C:)
10:53

Display the graphical plot full size by double clicking on its window title bar.


MBAL 8.00 - IPM 5.00 - Material Balance - 1.mbi - [Graphical Method]
Finish Replot Scales Display Output Window Input Method Best Fit Sampling Help
Method : (F-We)/Et versus F (Campbell)
640
600
560
520
480
0
50
100
150
200
(F-We)/Et (MMSTB)
F (MMRB)
2
3
4
5
6
7
8
9
10
11

X: 114.25
Y: 627.22
Oil in Place : 311.6 (MMSTB)

The graphical plots are based on the basic material balance formula:

$$F = N*Et + We$$

Where

F = Total Production
We = Water Influx
Et = Total Expansion
N = Original Oil in Place

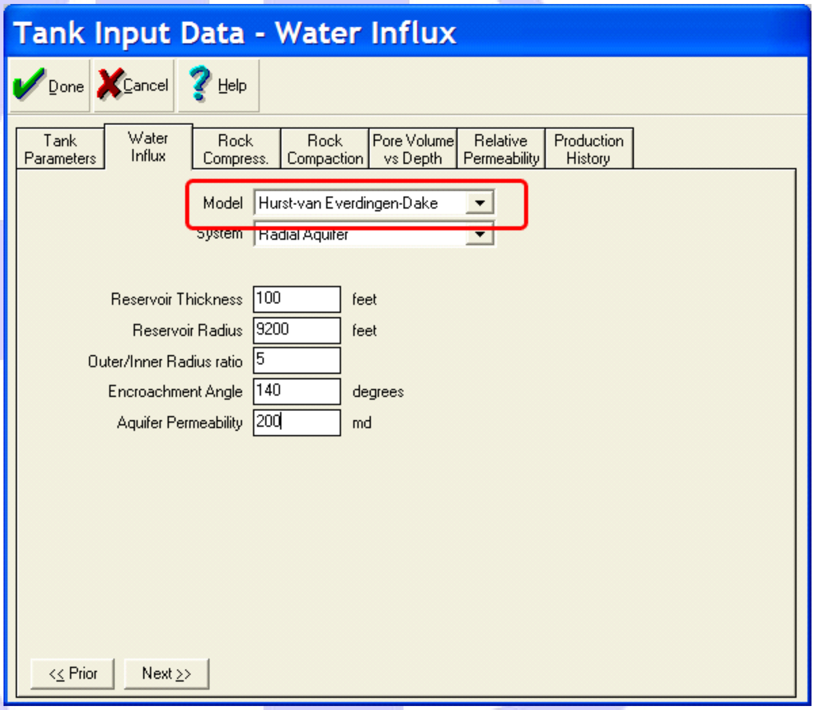
The **Campbell** method is displayed by default. This plot displays:

(F – We)/Et vs. F

(F-We)/Et is the STOIIP which is displayed along the y-axis. This value cannot change, therefore, if every contributing factor to the historical data had been accounted for, the value should be plotted as a horizontal straight line.

The increasing trend in the data on the Campbell plot suggests that a piece of information is still required for the system to be accurate. In this case, the only information not yet defined is the term, 'We', the water influx which means that an aquifer needs to be added to the model.

Going back to the tank input data screen, an aquifer is selected based on Dake’s recommendation:

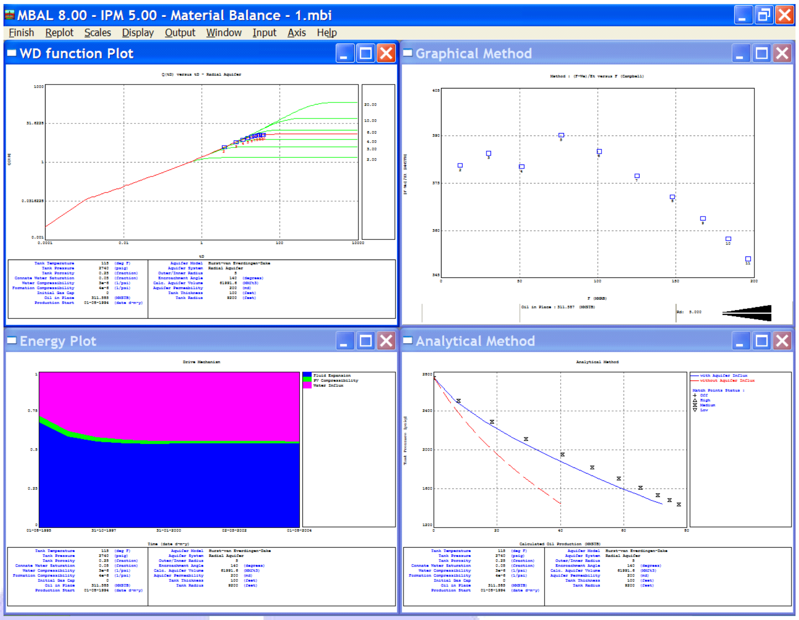

Done
Cancel
Help
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
<< Prior
Next >>

Tank Input Data - Water Influx

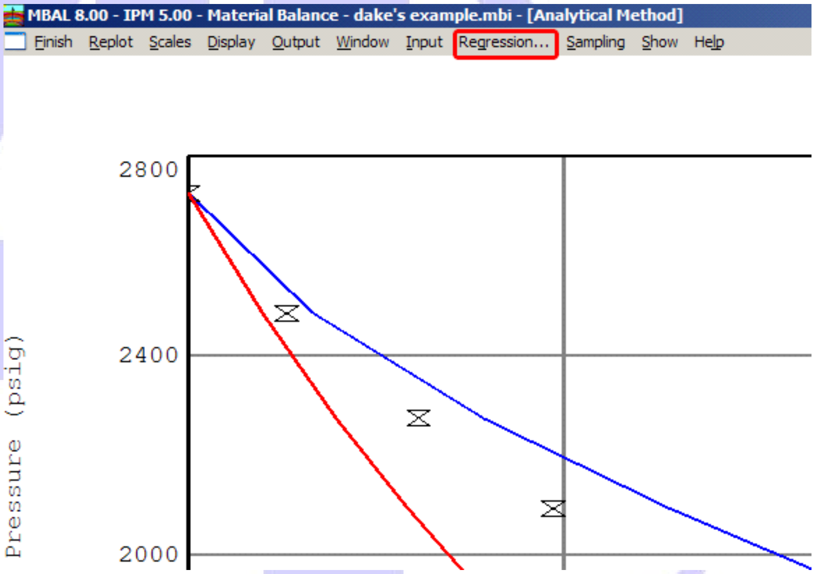
Model: Hurst-van Everdingen-Dake
System: Radial Aquifer

Reservoir Thickness: 100 feet
Reservoir Radius: 9200 feet
Outer/Inner Radius ratio: 5
Encroachment Angle: 140 degrees
Aquifer Permeability: 200 md

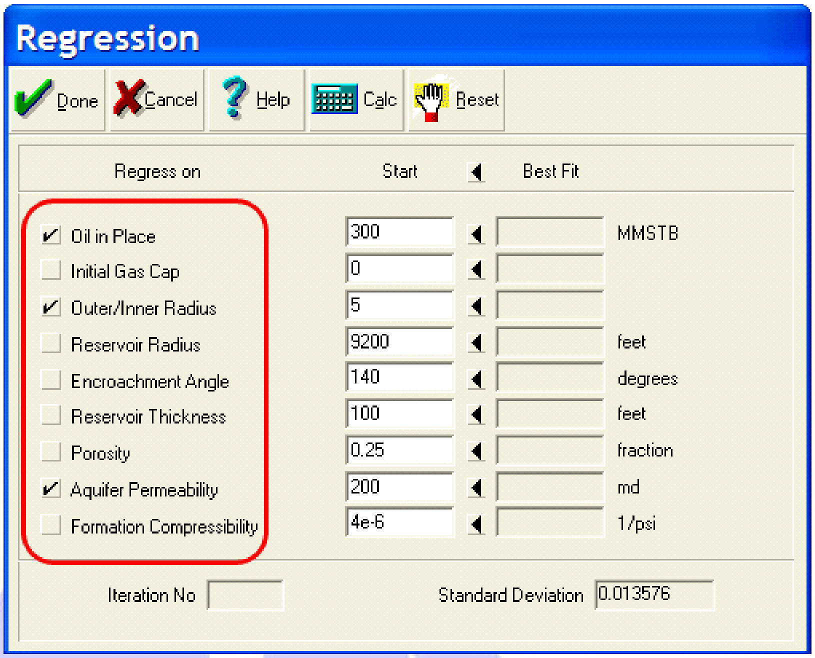
Going back to the “History Matching/All” page:


MBAL 8.00 - IPM 5.00 - Material Balance - 1.mbi
Finish Replot Scales Display Output Window Input Axis Help
WD function Plot
Graphical Method
Energy Plot
Analytical Method

On the Analytical method, we select the “Regression” option:


MBAL 8.00 - IPM 5.00 - Material Balance - dake's example.mbi - [Analytical Method]
Finish Replot Scales Display Output Window Input Regression... Sampling Show Help
2800
2400
2000
Pressure (psig)

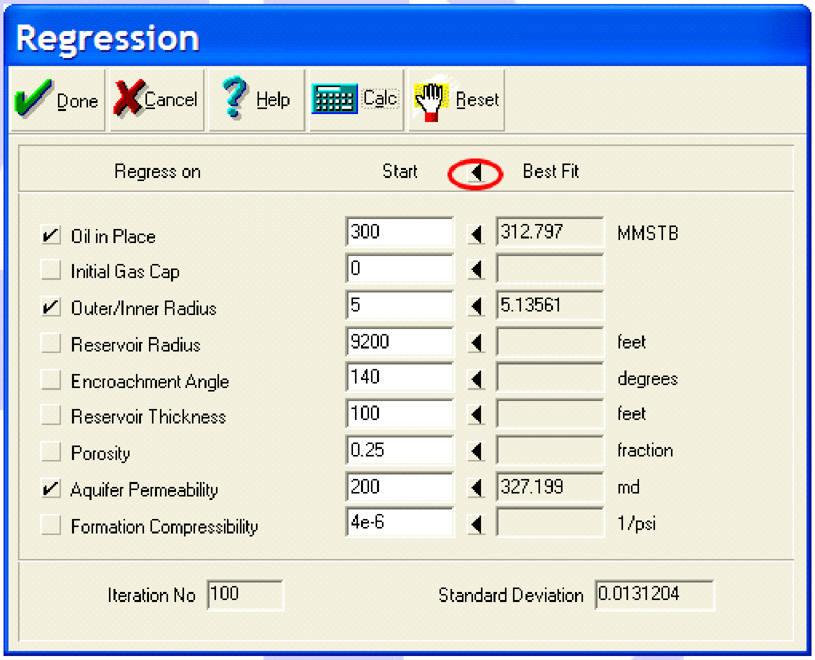
On the regression screen, the variables which we are least sure of are selected:



Regress on	Start	Best Fit	
☑ Oil in Place	300		MMSTB
☐ Initial Gas Cap	0		
☑ Outer/Inner Radius	5		
☐ Reservoir Radius	9200		feet
☐ Encroachment Angle	140		degrees
☐ Reservoir Thickness	100		feet
☐ Porosity	0.25		fraction
☑ Aquifer Permeability	200		md
☐ Formation Compressibility	4e-6		1/psi

Iteration No

Standard Deviation 0.013576

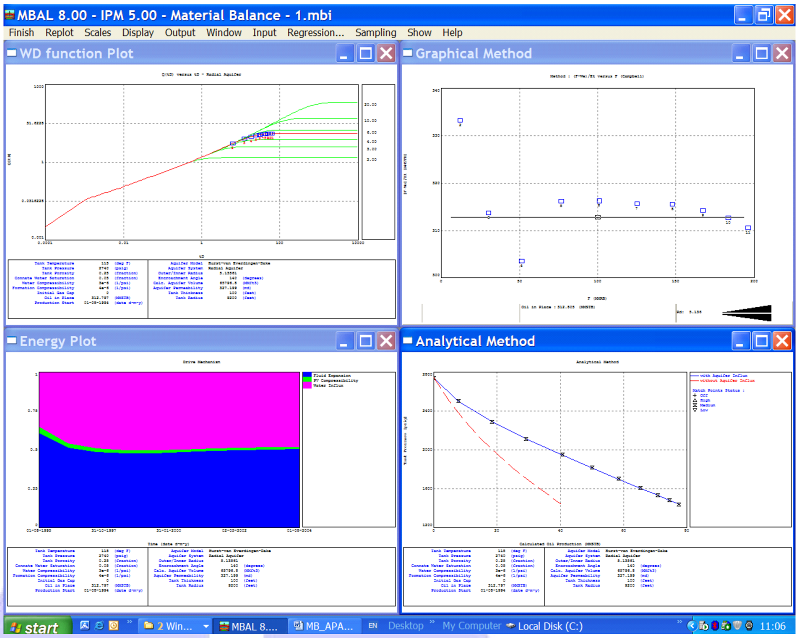


Regress on	Start	Best Fit	
☑ Oil in Place	300	312.797	MMSTB
☐ Initial Gas Cap	0		
☑ Outer/Inner Radius	5	5.13561	
☐ Reservoir Radius	9200		feet
☐ Encroachment Angle	140		degrees
☐ Reservoir Thickness	100		feet
☐ Porosity	0.25		fraction
☑ Aquifer Permeability	200	327.199	md
☐ Formation Compressibility	4e-6		1/psi

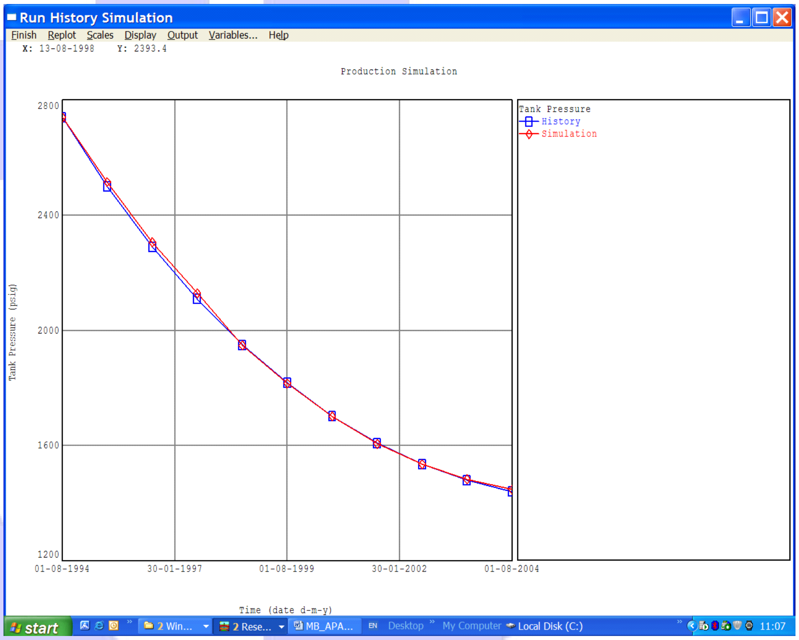
Iteration No 100

Standard Deviation 0.0131204

The best-fit button above will transfer all of the calculated data onto the model and the necessary updates will be performed automatically when “Done” is clicked.


MBAL 8.00 - IPM 5.00 - Material Balance - 1.mbi
Finish Replot Scales Display Output Window Input Regression... Sampling Show Help
WD function Plot
Graphical Method
Energy Plot
Analytical Method
start
11:06

Having determined; the presence of an aquifer, its size and impact as well as the STOIIP, calculations with this data in use can now be carried out. Before moving onto predictions and forecasts, it is possible to compare the measured historical data with the calculations run by **MBAL**. In other words, a verification can be carried out to ensure that when material balance is in use with the regressed data (aquifer parameters etc.) that the historical data is reproduced. This is carried out from History Matching|Run Simulation:


Run History Simulation
Finish Replot Scales Display Output Variables... Help
X: 13-08-1998 Y: 2393.4
Production Simulation
2800
2400
2000
1600
1200
Tank Pressure (psig)
01-08-1994
30-01-1997
01-08-1999
30-01-2002
01-08-2004
Time (date d-m-y)
Tank Pressure
History
Simulation
start
11:07

It can be seen that the match is good and therefore the calculations carried out by **MBAL** can be relied upon to represent the reality observed within the system.

The following is a comparison of the results in Dake and the results of **MBAL**:

	Dake	**MBAL**
OOIP	312 MMstb	312.28 MMstb
Outer Inner Radius	5	5.13

3.2.8 Well by Well History Matching

A fundamental issue in forward predictions using material balance principles is the accurate forecast of water cut and GOR (free gas from gas cap). As no geological model exists, **MBAL** uses pseudo relative permeability curves, from which fractional flow is calculated as a function of saturation.

In the Fw / Fg / Fo matching 252 section, the matching of “reservoir wide” pseudo rel perms was illustrated. In a case where many wells exist in the system, different water cuts will be produced from each well and this behaviour will need to be captured through individual rel perm curves.

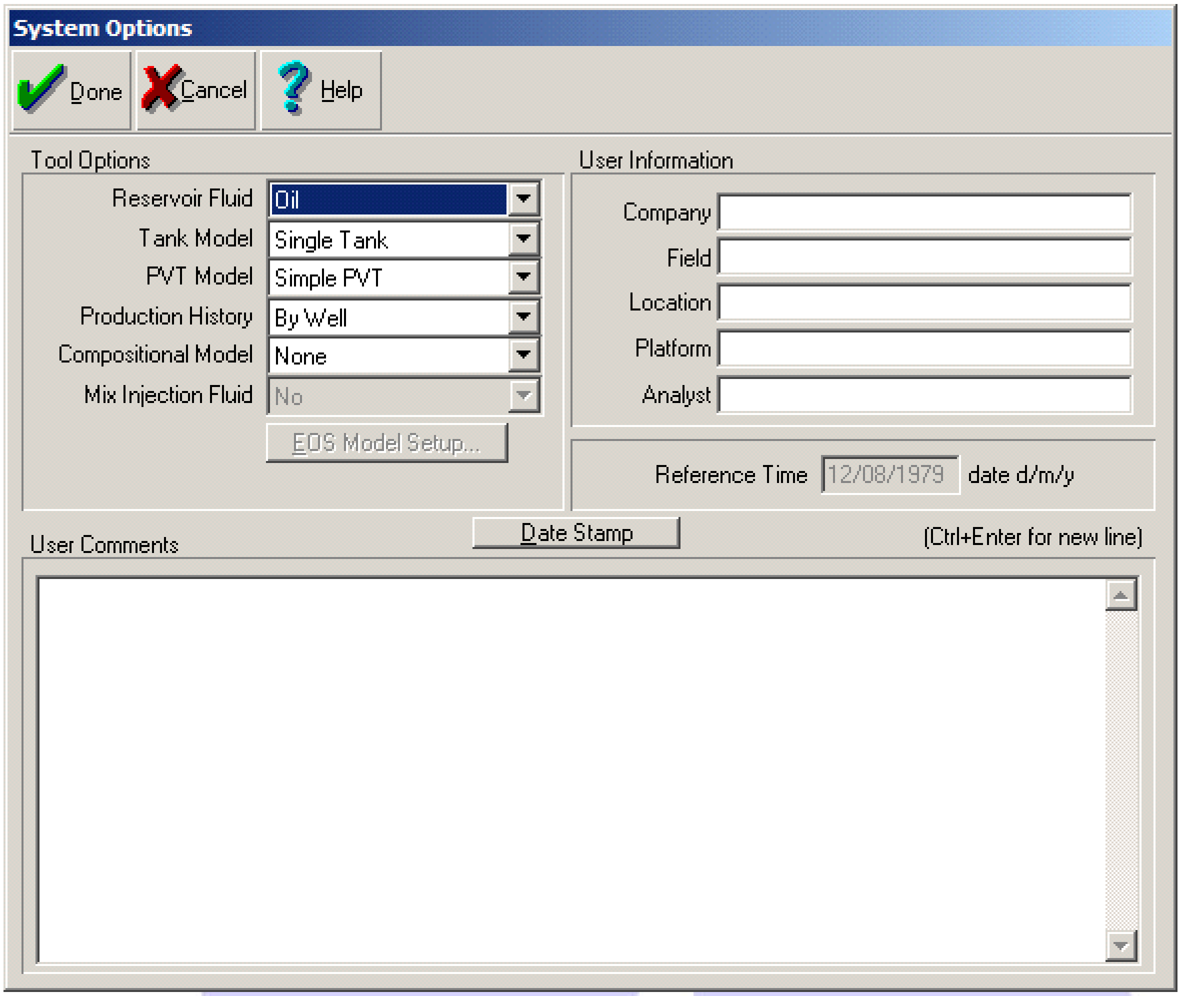
This example will show how historical data can be entered on a well by well basis, which will in turn allow one set of pseudo relative permeabilities to be created for each well in the system.

The files for this example are located in: C:\Program Files\Petroleum Experts\IPM 7\Samples\MBAL\History Well By Well.

Please note that all of the PVT and basic history data have already been entered in the model and we will only concentrate on entering the historical data, history matching and creating the rel perms on a well by well basis.

Step1. Activating the Options

Under the Options Menu the production history is defined as 'By Well':


System Options
Done
Cancel
Help
EOS Model Setup...
Date Stamp

Tool Options

Reservoir Fluid: Oil
Tank Model: Single Tank
PVT Model: Simple PVT
Production History: By Well
Compositional Model: None
Mix Injection Fluid: No

User Information

Company:
Field:
Location:
Platform:
Analyst:

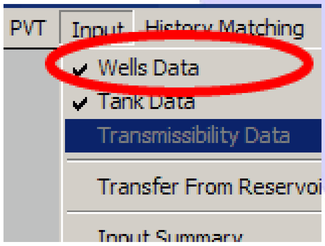
Reference Time: 12/08/1979 date d/m/y

User Comments (Ctrl+Enter for new line)

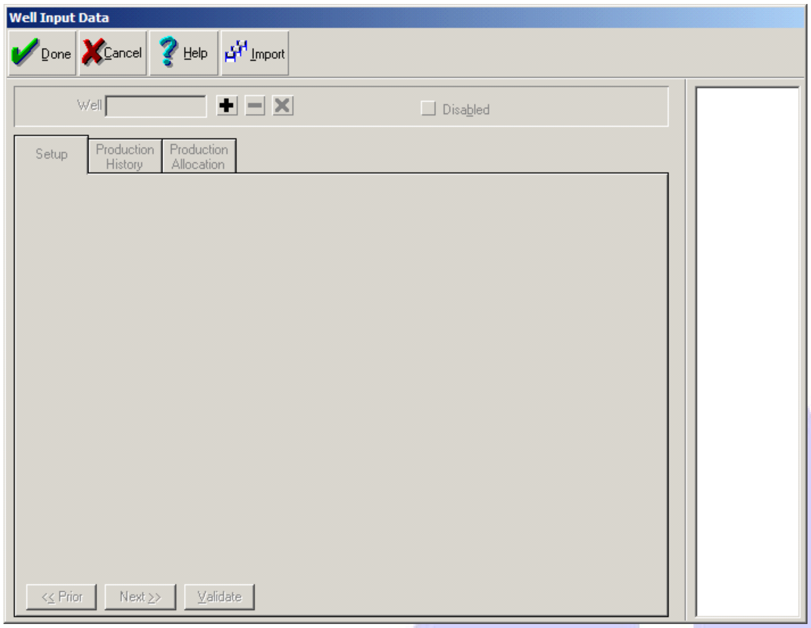
This option allows for the historical data for each well to be entered.

Step 2. Creating history wells

Selecting “Input/Wells Data” as shown:

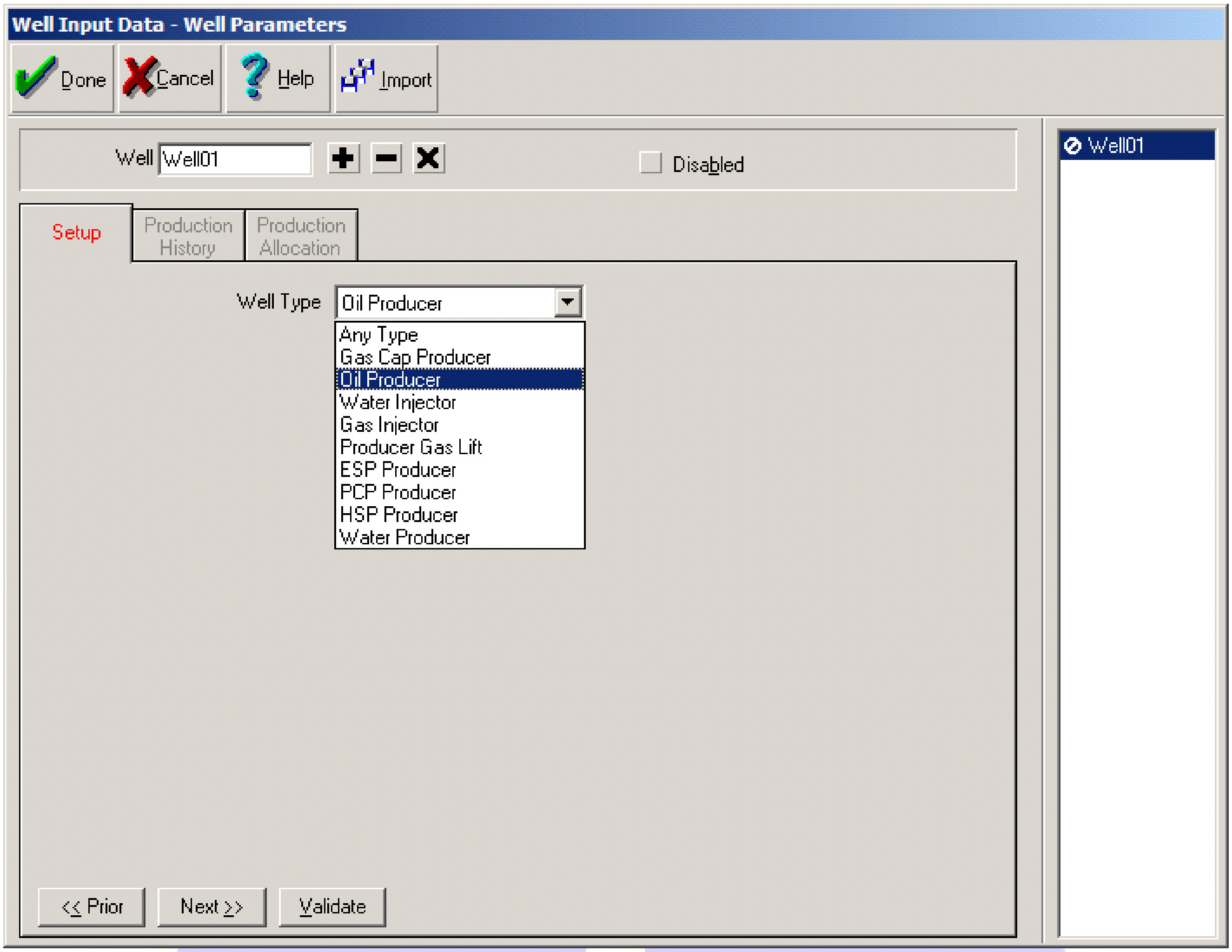

PVT
Input
History Matching
Wells Data
Tank Data
Transmissibility Data
Transfer From Reservoi
Input Summary

This results in the following screen, in which a history well can be created by selecting the + button:

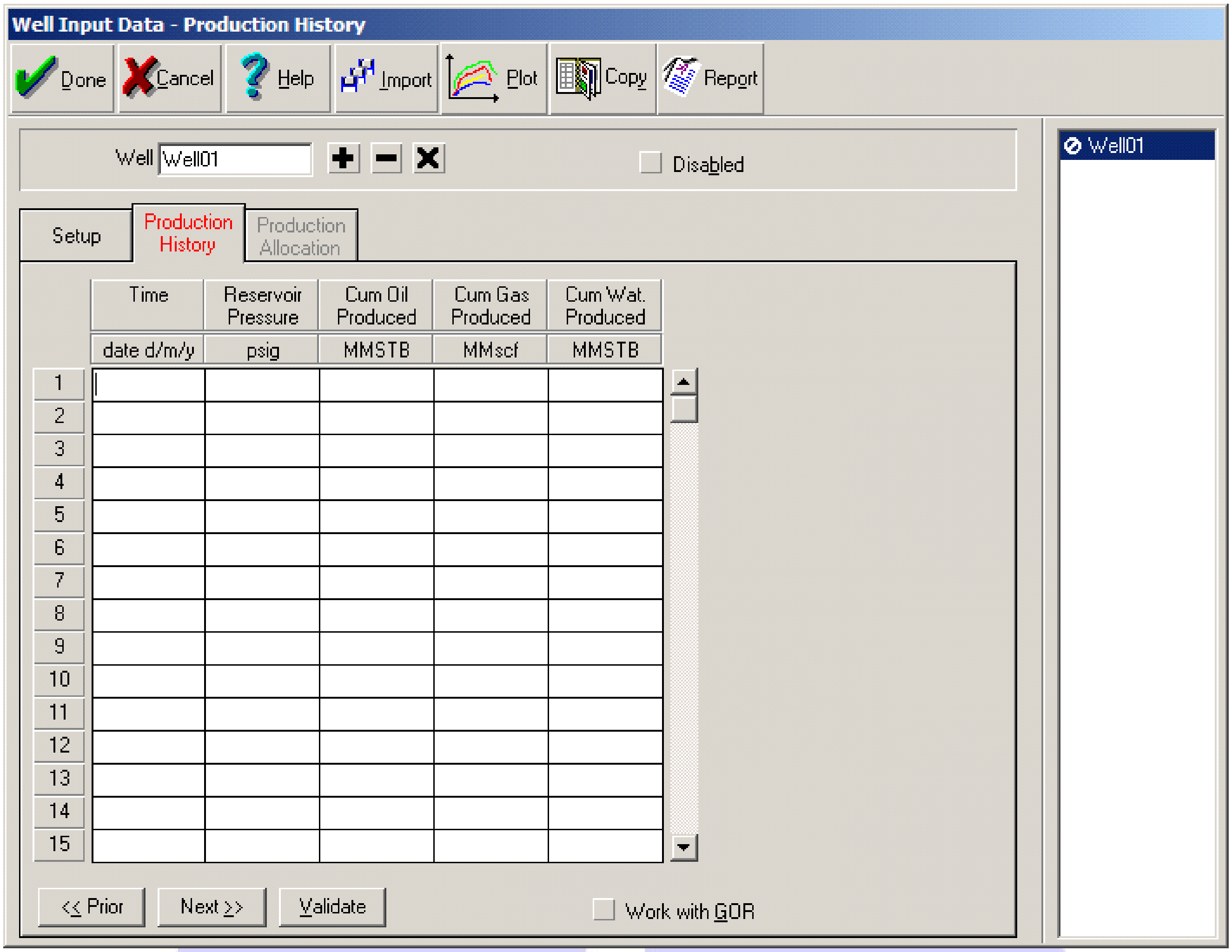

Well Input Data
Done
Cancel
Help
Import
Well
Disabled
Setup
Production History
Production Allocation
<< Prior
Next >>
Validate

This will create the well and open the well Setup screen as shown below.
A history well in **MBAL** is defined within the; Setup Screen, the production history screen and the production allocation screen (defining how much each reservoir contributed to the total production in multi layer systems).

As soon as the well is created, then the type of production from this well needs to be selected. The drop down menu below provides different types of well **MBAL** can handle:


Well Input Data - Well Parameters
Done
Cancel
Help
Import
Well
Well01
Disabled
Setup
Production History
Production Allocation
Well Type
Oil Producer
Any Type
Gas Cap Producer
Oil Producer
Water Injector
Gas Injector
Producer Gas Lift
ESP Producer
PCP Producer
HSP Producer
Water Producer
<< Prior
Next >>
Validate
Well01

The well is selected as an “Oil Producer” and the “Next” button will lead us to the production history screen:


Well Input Data - Production History
Done
Cancel
Help
Import
Plot
Copy
Report
Setup
Production History
Production Allocation
<< Prior
Next >>
Validate
Well01

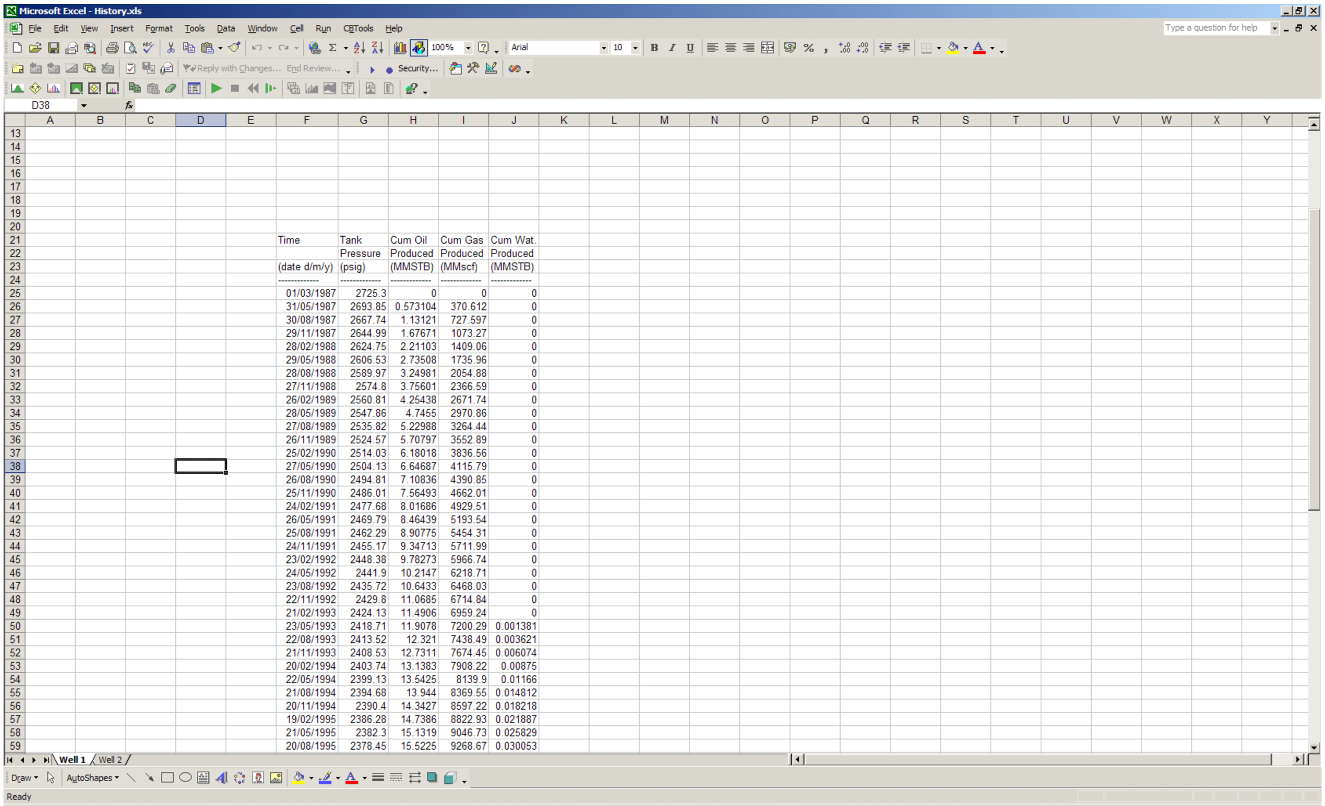
Well Well01

☐ Disabled

	Time	Reservoir Pressure	Cum Oil Produced	Cum Gas Produced	Cum Wat. Produced
	date d/m/y	psig	MMSTB	MMscf	MMSTB
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					

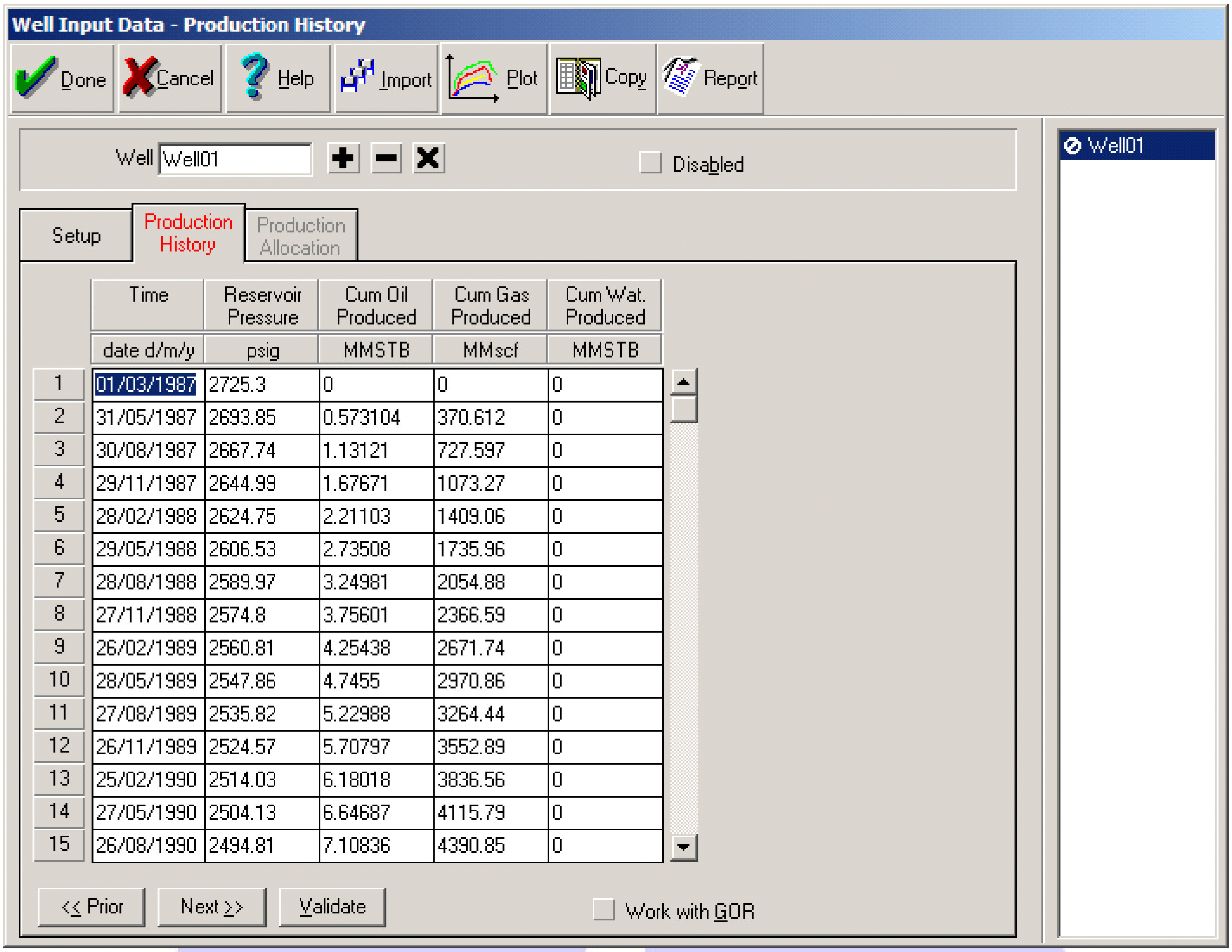
☐ Work with GOR

The production history can be copied and pasted directly from Excel. This can be found in the spreadsheet called “History”, under the “History Well by Well” folder in the **MBAL** samples directory. In this spreadsheet, there are two worksheets, each containing the production history of the two wells that will be built into this system:


Microsoft Excel - History.xls
File Edit View Insert Format Tools Data Window Cell Run CBTools Help
D38
Well 1
Well 2
Ready

Time (date d/m/y)	Tank Pressure (psig)	Cum Oil Produced (MMSTB)	Cum Gas Produced (MMscf)	Cum Wat. Produced (MMSTB)
------------	------------	------------	------------	------------
01/03/1987	2725.3	0	0	0
31/05/1987	2693.85	0.573104	370.612	0
30/08/1987	2667.74	1.13121	727.597	0
29/11/1987	2644.99	1.67671	1073.27	0
28/02/1988	2624.75	2.21103	1409.06	0
29/05/1988	2606.53	2.73508	1735.96	0
28/08/1988	2589.97	3.24981	2054.88	0
27/11/1988	2574.8	3.75601	2366.59	0
26/02/1989	2560.81	4.25438	2671.74	0
28/05/1989	2547.86	4.7455	2970.86	0
27/08/1989	2535.82	5.22988	3264.44	0
26/11/1989	2524.57	5.70797	3552.89	0
25/02/1990	2514.03	6.18018	3836.56	0
27/05/1990	2504.13	6.64687	4115.79	0
26/08/1990	2494.81	7.10836	4390.85	0
25/11/1990	2486.01	7.56493	4662.01	0
24/02/1991	2477.68	8.01686	4929.51	0
26/05/1991	2469.79	8.46439	5193.54	0
25/08/1991	2462.29	8.90775	5454.31	0
24/11/1991	2455.17	9.34713	5711.99	0
23/02/1992	2448.38	9.78273	5966.74	0
24/05/1992	2441.9	10.2147	6218.71	0
23/08/1992	2435.72	10.6433	6468.03	0
22/11/1992	2429.8	11.0685	6714.84	0
21/02/1993	2424.13	11.4906	6959.24	0
23/05/1993	2418.71	11.9078	7200.29	0.001381
22/08/1993	2413.52	12.321	7438.49	0.003621
21/11/1993	2408.53	12.7311	7674.45	0.006074
20/02/1994	2403.74	13.1383	7908.22	0.00875
22/05/1994	2399.13	13.5425	8139.9	0.01166
21/08/1994	2394.68	13.944	8369.55	0.014812
20/11/1994	2390.4	14.3427	8597.22	0.018218
19/02/1995	2386.28	14.7386	8822.93	0.021887
21/05/1995	2382.3	15.1319	9046.73	0.025829
20/08/1995	2378.45	15.5225	9268.67	0.030053

The history that needs to be copied into the well in **MBAL** is the one corresponding to well 1.


Done
Cancel
Help
Import
Plot
Copy
Report
Setup
Production History
Production Allocation
<< Prior
Next >>
Validate

Well Input Data - Production History

Well Well01

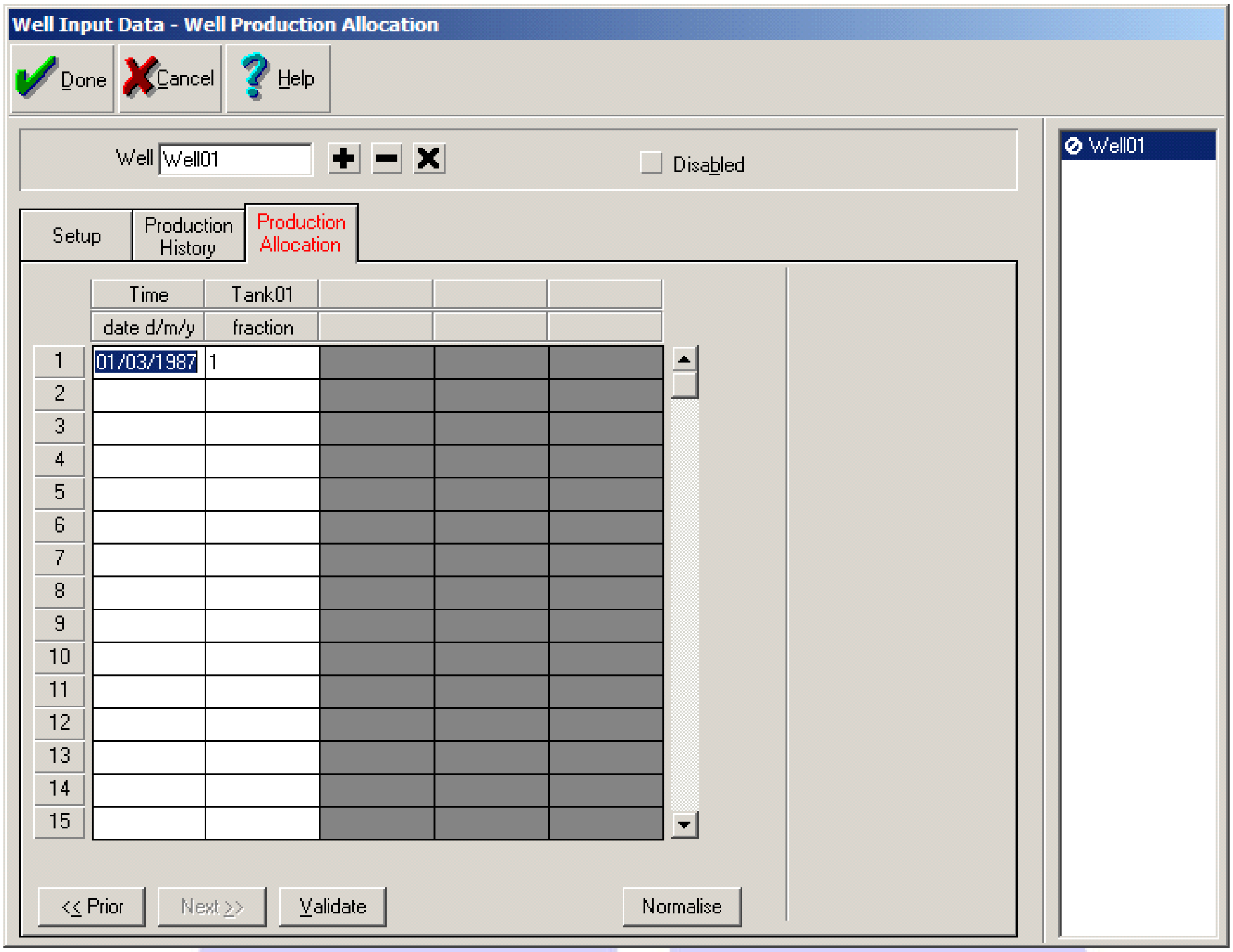
☐ Disabled

	Time	Reservoir Pressure	Cum Oil Produced	Cum Gas Produced	Cum Wat. Produced
	date d/m/y	psig	MMSTB	MMscf	MMSTB
1	01/03/1987	2725.3	0	0	0
2	31/05/1987	2693.85	0.573104	370.612	0
3	30/08/1987	2667.74	1.13121	727.597	0
4	29/11/1987	2644.99	1.67671	1073.27	0
5	28/02/1988	2624.75	2.21103	1409.06	0
6	29/05/1988	2606.53	2.73508	1735.96	0
7	28/08/1988	2589.97	3.24981	2054.88	0
8	27/11/1988	2574.8	3.75601	2366.59	0
9	26/02/1989	2560.81	4.25438	2671.74	0
10	28/05/1989	2547.86	4.7455	2970.86	0
11	27/08/1989	2535.82	5.22988	3264.44	0
12	26/11/1989	2524.57	5.70797	3552.89	0
13	25/02/1990	2514.03	6.18018	3836.56	0
14	27/05/1990	2504.13	6.64687	4115.79	0
15	26/08/1990	2494.81	7.10836	4390.85	0

☐ Work with GOR

Well01

The “Next” button will then lead to the “Production Allocation” page:


Well Input Data - Well Production Allocation
Done
Cancel
Help
Well
Disabled
Setup
Production History
Production Allocation
<< Prior
Next >>
Validate
Normalise
Well01

Well: Well01

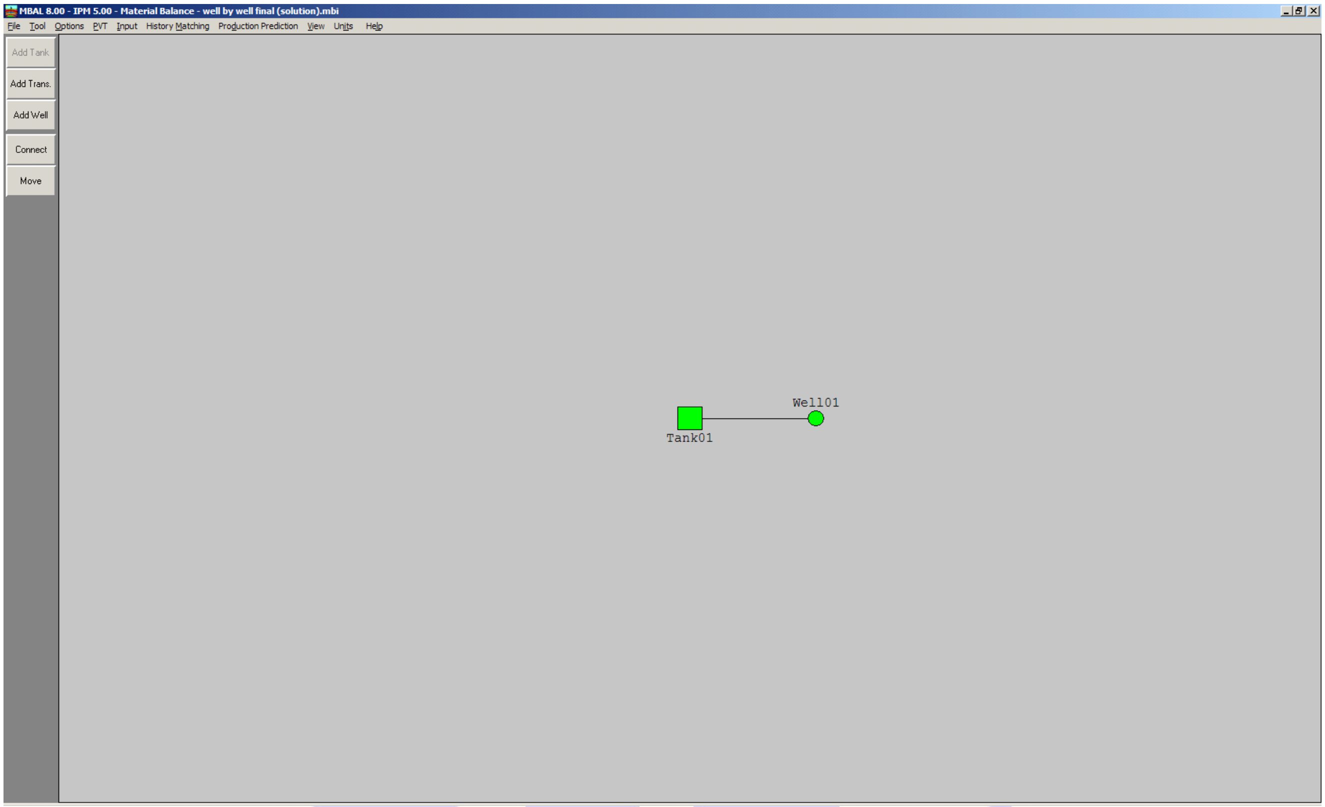
☐ Disabled

	Time	Tank01
	date d/m/y	fraction
1	01/03/1987	1
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		

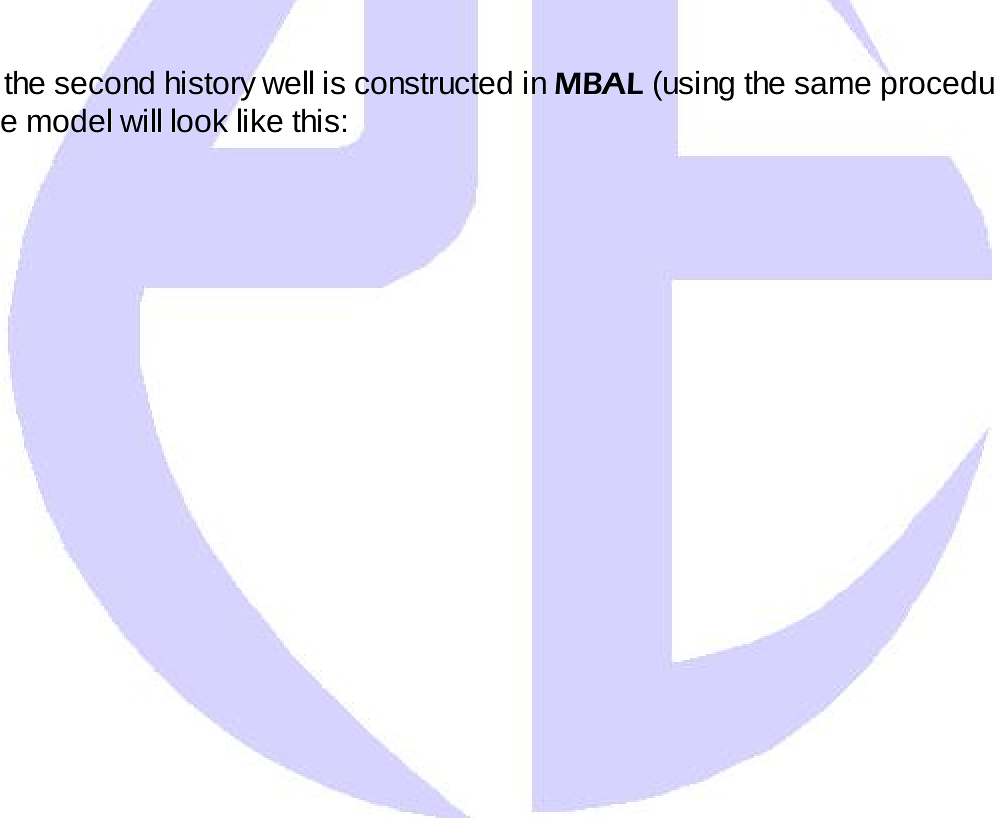
In this screen, the program is informed that all of the production entered as history in the well comes from the same reservoir. In multilayer systems where the well is connected to more than one reservoir (layers), then the allocation needs to be carried out before this screen is invoked.

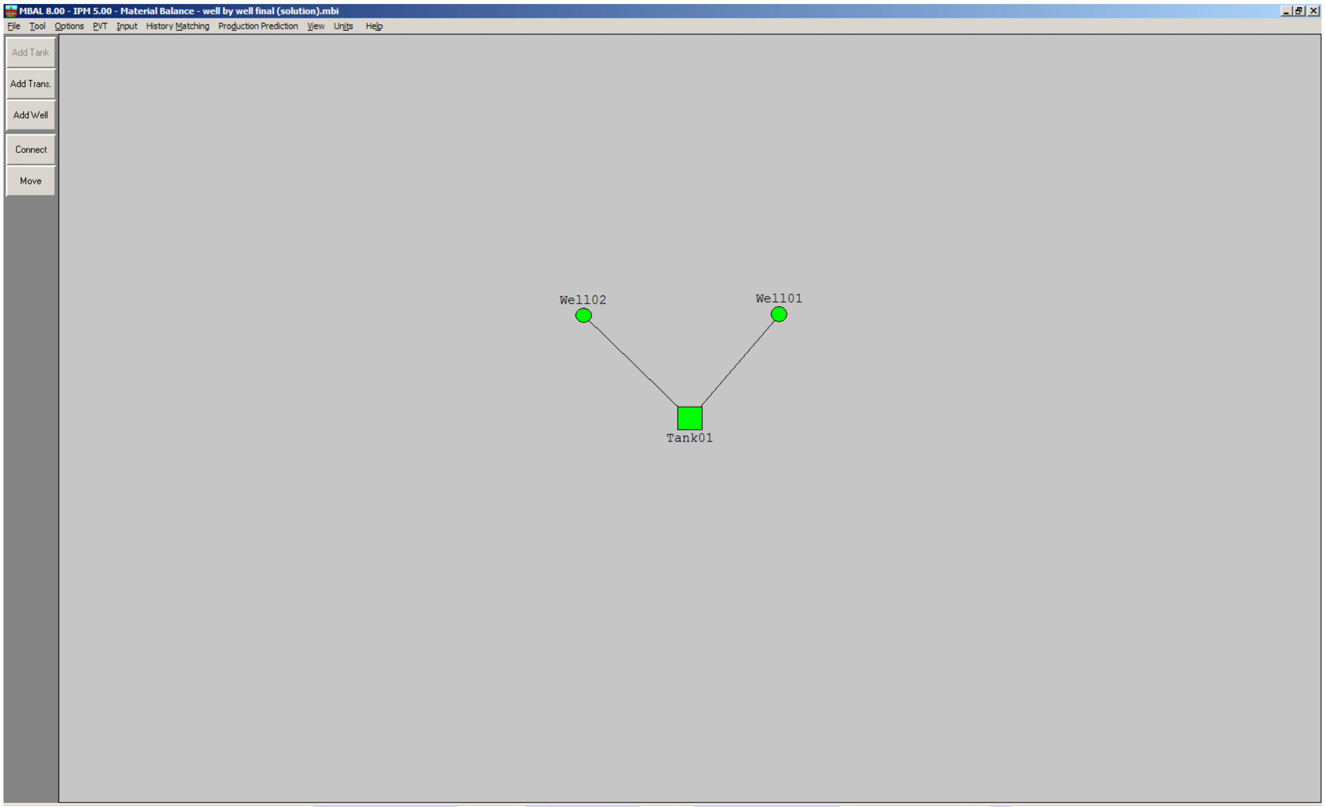
Note: In multilayer systems, MBAL has a tool specifically designed to calculate the layer by layer allocation. This tool is called "Production Allocation" and uses an approach based on IPRs and rates of depletion rather than simply a kh allocation.

Now the model will look like this:


MBAL 8.00 - IPM 5.00 - Material Balance - well by well final (solution).mbi
File Tool Options PVT Input History Matching Production Prediction View Units Help
Add Tank
Add Trans.
Add Well
Connect
Move
Well01
Tank01

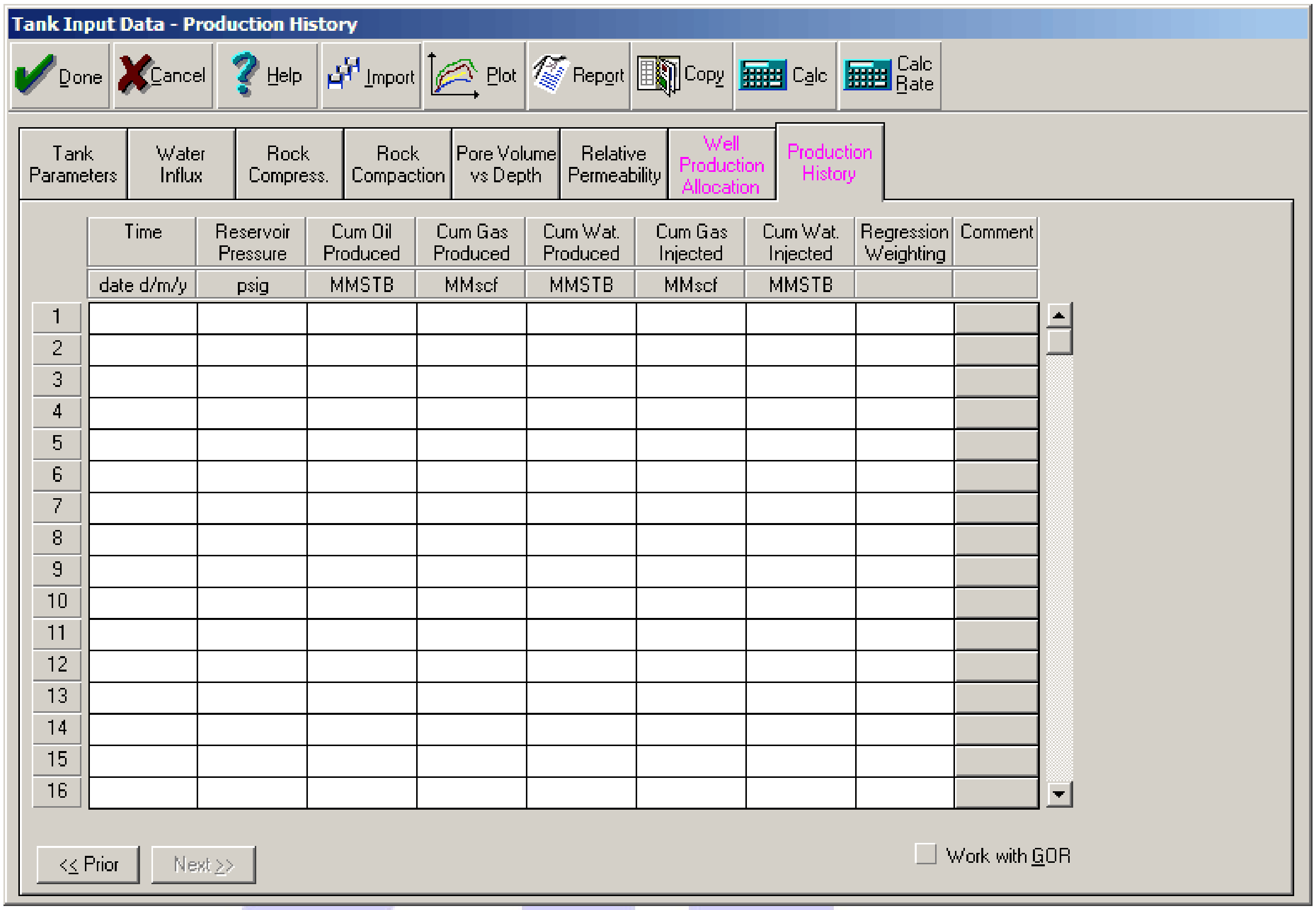
As soon as the second history well is constructed in **MBAL** (using the same procedure as for the first well), the model will look like this:




MBAL 8.00 - IPM 5.00 - Material Balance - well by well final (solution).mbi
File Tool Options PVT Input History Matching Production Prediction View Units Help
Add Tank
Add Trans.
Add Well
Connect
Move
Well02
Well01
Tank01

Step 3: Transferring the production to the tanks

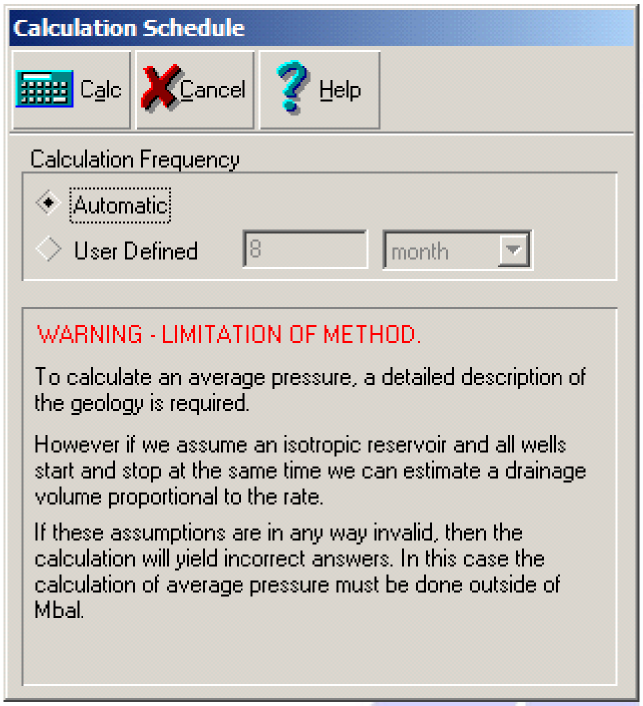
Now that both history wells have been constructed, the historical production needs to be transferred to the reservoir model so that history matching can be carried out. Moving to the tank “Production History screen:


Tank Input Data - Production History
Done
Cancel
Help
Import
Plot
Report
Copy
Calc
Calc Rate
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Well Production Allocation
Production History
<< Prior
Next >>
☐ Work with GOR

	Time	Reservoir Pressure	Cum Oil Produced	Cum Gas Produced	Cum Wat. Produced	Cum Gas Injected	Cum Wat. Injected	Regression Weighting	Comment
	date d/m/y	psig	MMSTB	MMscf	MMSTB	MMscf	MMSTB		
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									

It can be seen here that there are two buttons that only appear if the history is entered on a well by well basis. The program can now sum up the cumulatives entered in the two wells if the "**Calc**" button is selected:

Note: If 'Calc Rate' or 'Calc' is selected, the following warning message will be prompted, relating to the limitation of the method used to average the reservoir pressures:



Calculation Frequency

● Automatic

○ User Defined 8 month

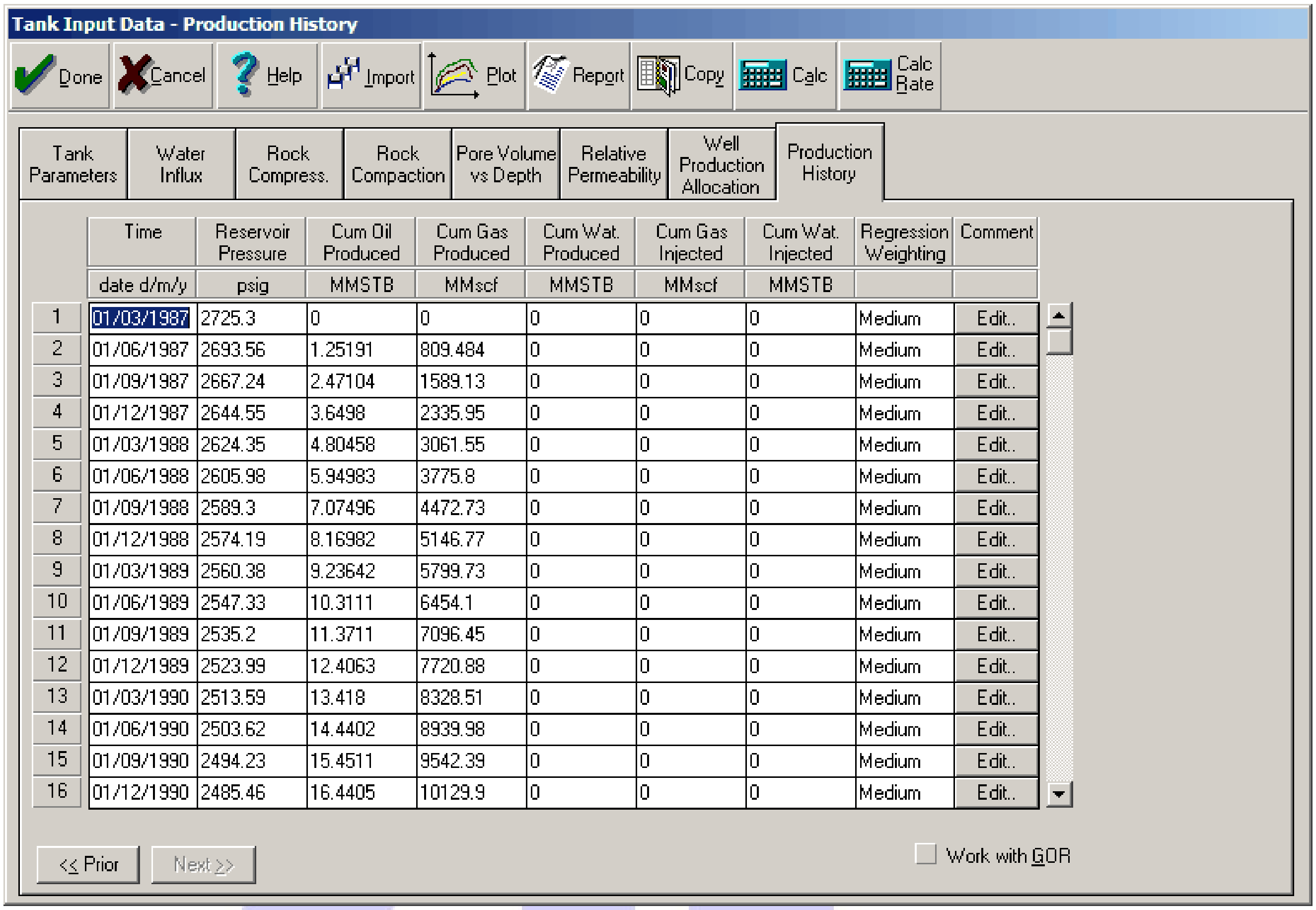
WARNING - LIMITATION OF METHOD.

To calculate an average pressure, a detailed description of the geology is required.

However if we assume an isotropic reservoir and all wells start and stop at the same time we can estimate a drainage volume proportional to the rate.

If these assumptions are in any way invalid, then the calculation will yield incorrect answers. In this case the calculation of average pressure must be done outside of Mbal.

Selecting “Calc” will now allow the program to perform the calculations. The reservoir pressures will now be averaged and the cumulatives added in order to capture the total production from the reservoir:

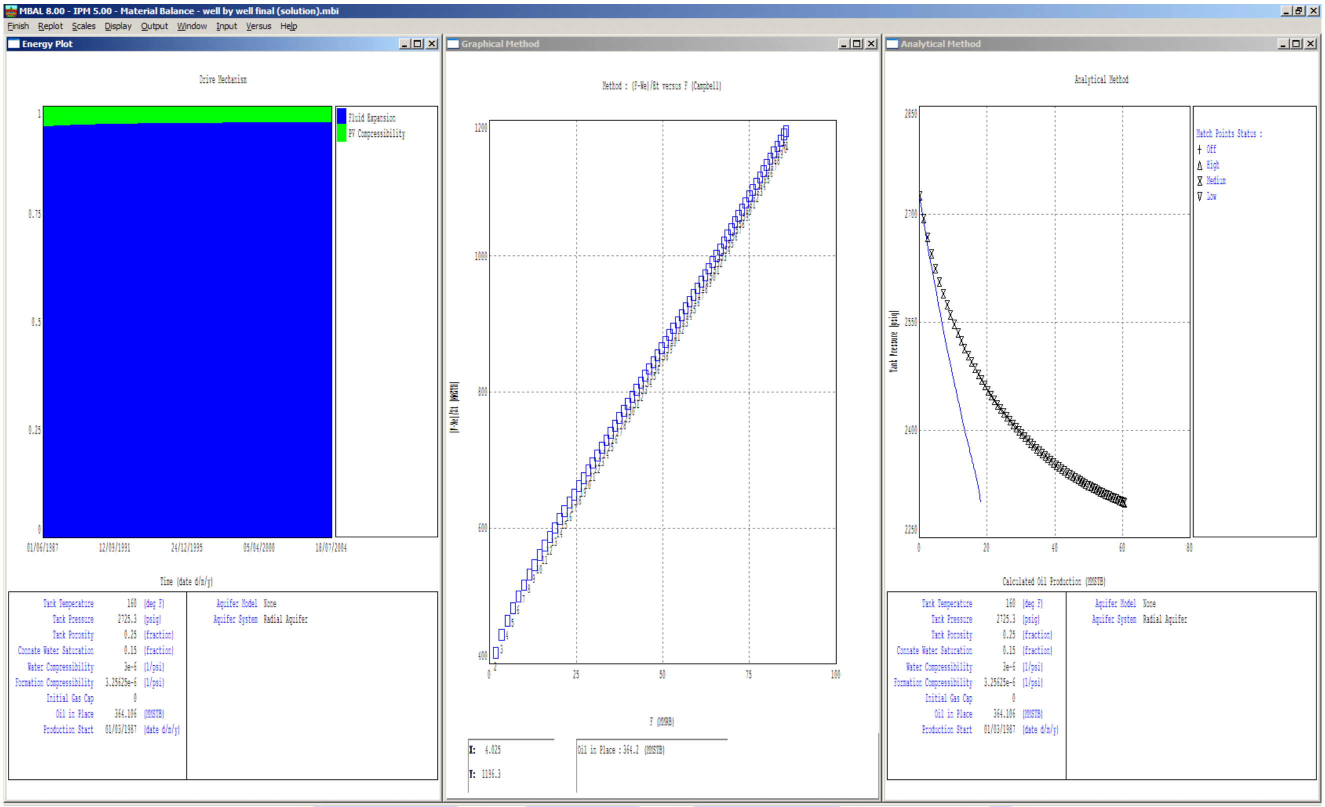

Tank Input Data - Production History
Done
Cancel
Help
Import
Plot
Report
Copy
Calc
Calc Rate
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Well Production Allocation
Production History
<< Prior
Next >>

	Time	Reservoir Pressure	Cum Oil Produced	Cum Gas Produced	Cum Wat. Produced	Cum Gas Injected	Cum Wat. Injected	Regression Weighting	Comment
	date d/m/y	psig	MMSTB	MMscf	MMSTB	MMscf	MMSTB		
1	01/03/1987	2725.3	0	0	0	0	0	Medium	Edit..
2	01/06/1987	2693.56	1.25191	809.484	0	0	0	Medium	Edit..
3	01/09/1987	2667.24	2.47104	1589.13	0	0	0	Medium	Edit..
4	01/12/1987	2644.55	3.6498	2335.95	0	0	0	Medium	Edit..
5	01/03/1988	2624.35	4.80458	3061.55	0	0	0	Medium	Edit..
6	01/06/1988	2605.98	5.94983	3775.8	0	0	0	Medium	Edit..
7	01/09/1988	2589.3	7.07496	4472.73	0	0	0	Medium	Edit..
8	01/12/1988	2574.19	8.16982	5146.77	0	0	0	Medium	Edit..
9	01/03/1989	2560.38	9.23642	5799.73	0	0	0	Medium	Edit..
10	01/06/1989	2547.33	10.3111	6454.1	0	0	0	Medium	Edit..
11	01/09/1989	2535.2	11.3711	7096.45	0	0	0	Medium	Edit..
12	01/12/1989	2523.99	12.4063	7720.88	0	0	0	Medium	Edit..
13	01/03/1990	2513.59	13.418	8328.51	0	0	0	Medium	Edit..
14	01/06/1990	2503.62	14.4402	8939.98	0	0	0	Medium	Edit..
15	01/09/1990	2494.23	15.4511	9542.39	0	0	0	Medium	Edit..
16	01/12/1990	2485.46	16.4405	10129.9	0	0	0	Medium	Edit..

☐ Work with GOR

Step 4: Performing the history match

The history matching can now be carried out as normal. Under “History Matching/All”, the relevant plots can be used to deduce possible drive mechanisms:


MBAL 8.00 - IPM 5.00 - Material Balance - well by well final (solution).mbi
Finish Replot Scales Display Output Window Input Versus Help
Energy Plot
Drive Mechanism
Fluid Expansion
PV Compressibility
1
0.75
0.5
0.25
0
01/06/1987
12/09/1991
24/12/1995
05/04/2000
18/07/2004
Time (date d/m/y)
Graphical Method
Method : (F-We)/Et versus F (Campbell)
1200
1000
800
600
400
0
25
50
75
100
(F-We)/Et (MMSTB)
F (MMRB)
Analytical Method
Analytical Method
Match Points Status :
+ Off
Δ High
⧖ Medium
∇ Low
2850
2700
2550
2400
2250
0
20
40
60
80
Tank Pressure (psig)
Calculated Oil Production (MMSTB)

Tank Temperature	160	(deg F)
Tank Pressure	2725.3	(psig)
Tank Porosity	0.25	(fraction)
Connate Water Saturation	0.15	(fraction)
Water Compressibility	3e-6	(1/psi)
Formation Compressibility	3.25625e-6	(1/psi)
Initial Gas Cap	0	
Oil in Place	364.106	(MMSTB)
Production Start	01/03/1987	(date d/m/y)

Aquifer Model None
Aquifer System Radial Aquifer

X: 4.025
Y: 1196.3

Oil in Place : 364.2 (MMSTB)

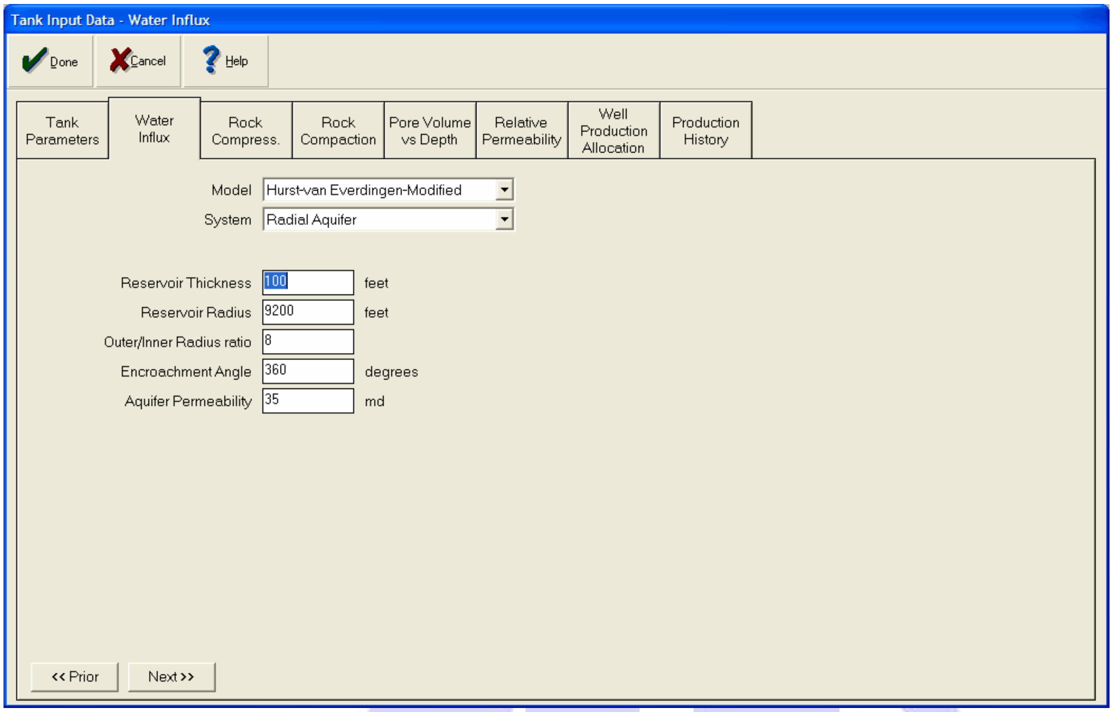
Tank Temperature	160	(deg F)
Tank Pressure	2725.3	(psig)
Tank Porosity	0.25	(fraction)
Connate Water Saturation	0.15	(fraction)
Water Compressibility	3e-6	(1/psi)
Formation Compressibility	3.25625e-6	(1/psi)
Initial Gas Cap	0	
Oil in Place	364.106	(MMSTB)
Production Start	01/03/1987	(date d/m/y)

Aquifer Model None
Aquifer System Radial Aquifer

Analysing the Campbell Plot, it can be seen that an aquifer support needs to be modelled. Click on 'Finish' and go back to the **Tank Input Data|Water Influx Tab** and enter the following information:

Model: Hurst Van Everdingen - Modified
System: Radial Aquifer
Reservoir Thickness : 100 ft
Reservoir Radius : 9200 ft
Outer Inner Radius Ratio : 8
Encroachment Angle: 360 degrees
Aquifer Permeability : 35 mD

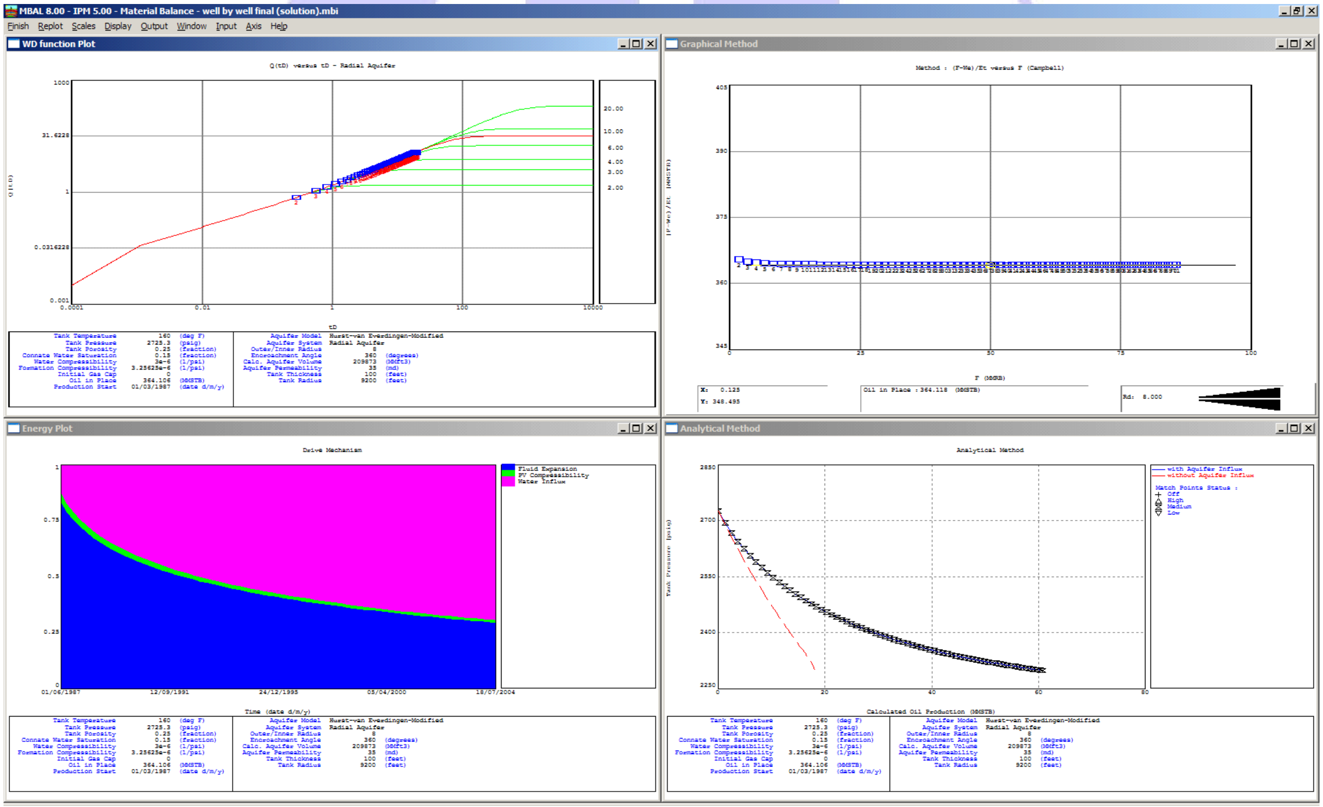
These values have been obtained to match the Campbell plot to the horizontal line. In the absence of aquifer data, the regression engine can be used to match the model. Information on the regression engine can be found in Example 1 above.


Tank Input Data - Water Influx
Done
Cancel
Help
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Well Production Allocation
Production History
<< Prior
Next >>

Model Hurst-van Everdingen-Modified
System Radial Aquifer

Reservoir Thickness 100 feet
Reservoir Radius 9200 feet
Outer/Inner Radius ratio 8
Encroachment Angle 360 degrees
Aquifer Permeability 35 md

Click on 'Done' and on the main screen of MBAL click on 'History Matching | All'. Four plots will be seen as shown below. The Campbell plot shows a good agreement to the horizontal line.


MBAL 8.00 - IPM 5.00 - Material Balance - well by well final (solution).mbi
Finish
Replot
Scales
Display
Output
Window
Input
Axis
Help
WD function Plot
Q(tD) versus tD - Radial Aquifer
Q(tD)
1000
31.6228
1
0.0316228
0.001
0.0001
0.01
1
100
10000
tD
20.00
10.00
6.00
4.00
3.00
2.00
Graphical Method
Method : (F-We)/Et versus F (Campbell)
(F-We)/Et (MMSTB)
405
390
375
360
345
0
25
50
75
100
F (MMRB)
Energy Plot
Drive Mechanism
1
0.75
0.5
0.25
0
01/06/1987
12/09/1991
24/12/1995
05/04/2000
18/07/2004
Time (date d/m/y)
Fluid Expansion
PV Compressibility
Water Influx
Analytical Method
Analytical Method
Tank Pressure (psig)
2850
2700
2550
2400
2250
0
20
40
60
80
Calculated Oil Production (MMSTB)
with Aquifer Influx
without Aquifer Influx
Match Points Status :
Off
High
Medium
Low

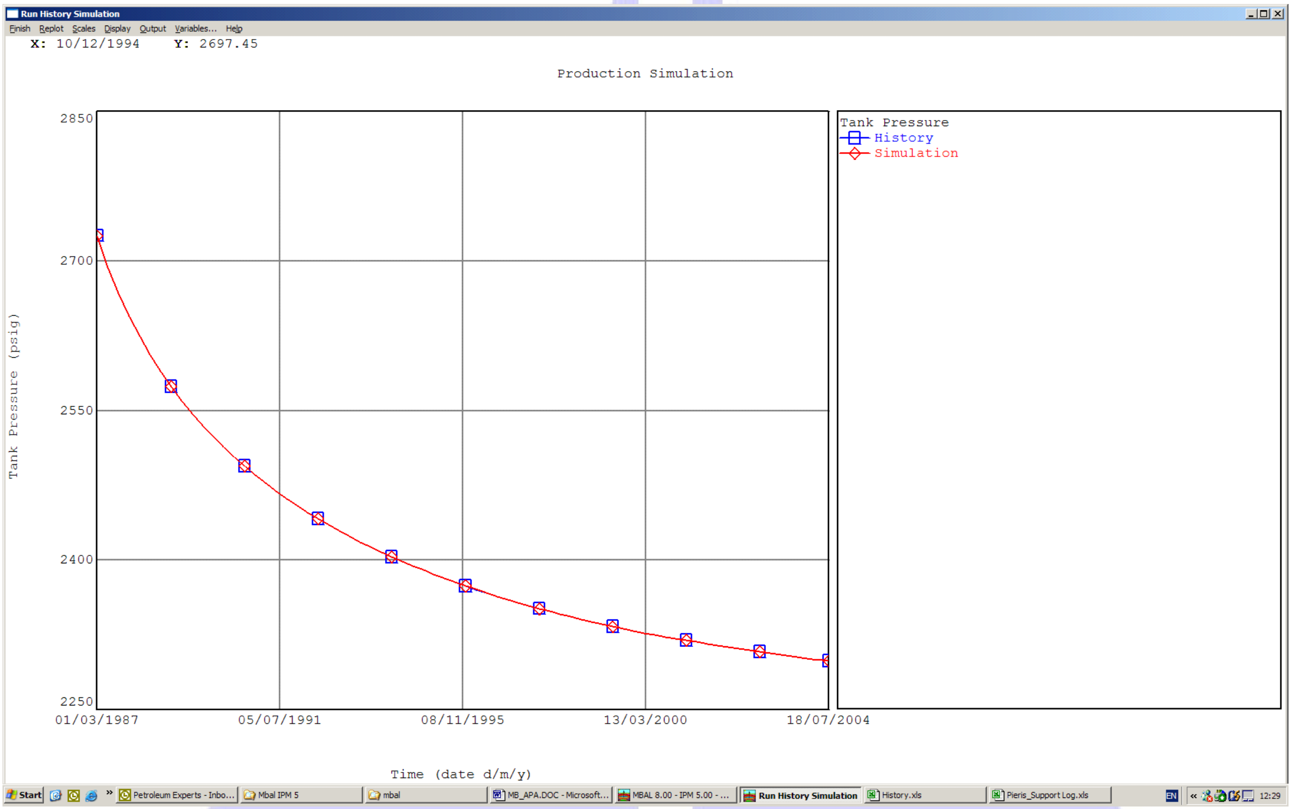
```
         Tank Temperature        160   (deg F)          Aquifer Model  Hurst-van Everdingen-Modified
            Tank Pressure     2725.3   (psig)          Aquifer System  Radial Aquifer
            Tank Porosity       0.25   (fraction)   Outer/Inner Radius        8
 Connate Water Saturation       0.15   (fraction)   Encroachment Angle      360   (degrees)
   Water Compressibility        3e-6   (1/psi)    Calc. Aquifer Volume   209873   (MMft3)
Formation Compressibility  3.25625e-6  (1/psi)    Aquifer Permeability       35   (md)
         Initial Gas Cap           0                    Tank Thickness      100   (feet)
            Oil in Place     364.106   (MMSTB)             Tank Radius     9200   (feet)
        Production Start  01/03/1987   (date d/m/y)
```

```
X:   0.125
Y: 348.495
Oil in Place : 364.118  (MMSTB)
Rd:  8.000
```

```
         Tank Temperature        160   (deg F)          Aquifer Model  Hurst-van Everdingen-Modified
            Tank Pressure     2725.3   (psig)          Aquifer System  Radial Aquifer
            Tank Porosity       0.25   (fraction)   Outer/Inner Radius        8
 Connate Water Saturation       0.15   (fraction)   Encroachment Angle      360   (degrees)
   Water Compressibility        3e-6   (1/psi)    Calc. Aquifer Volume   209873   (MMft3)
Formation Compressibility  3.25625e-6  (1/psi)    Aquifer Permeability       35   (md)
         Initial Gas Cap           0                    Tank Thickness      100   (feet)
            Oil in Place     364.106   (MMSTB)             Tank Radius     9200   (feet)
        Production Start  01/03/1987   (date d/m/y)
```

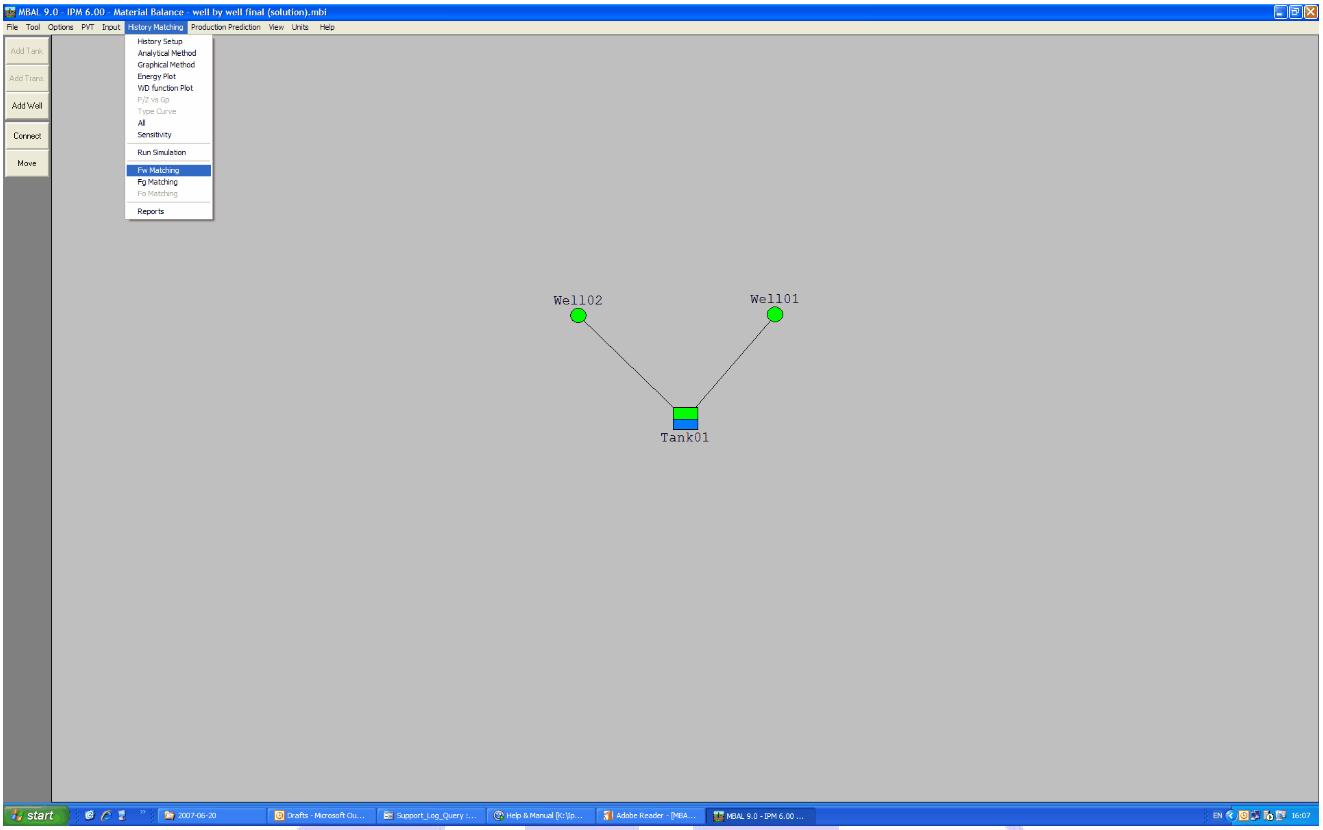
```
         Tank Temperature        160   (deg F)          Aquifer Model  Hurst-van Everdingen-Modified
            Tank Pressure     2725.3   (psig)          Aquifer System  Radial Aquifer
            Tank Porosity       0.25   (fraction)   Outer/Inner Radius        8
 Connate Water Saturation       0.15   (fraction)   Encroachment Angle      360   (degrees)
   Water Compressibility        3e-6   (1/psi)    Calc. Aquifer Volume   209873   (MMft3)
Formation Compressibility  3.25625e-6  (1/psi)    Aquifer Permeability       35   (md)
         Initial Gas Cap           0                    Tank Thickness      100   (feet)
            Oil in Place     364.106   (MMSTB)             Tank Radius     9200   (feet)
        Production Start  01/03/1987   (date d/m/y)
```

The results can also be confirmed with the “Simulation” feature. From the Main Screen of MBAL, click on **History Matching|Run Simulation|Calc|Plot**

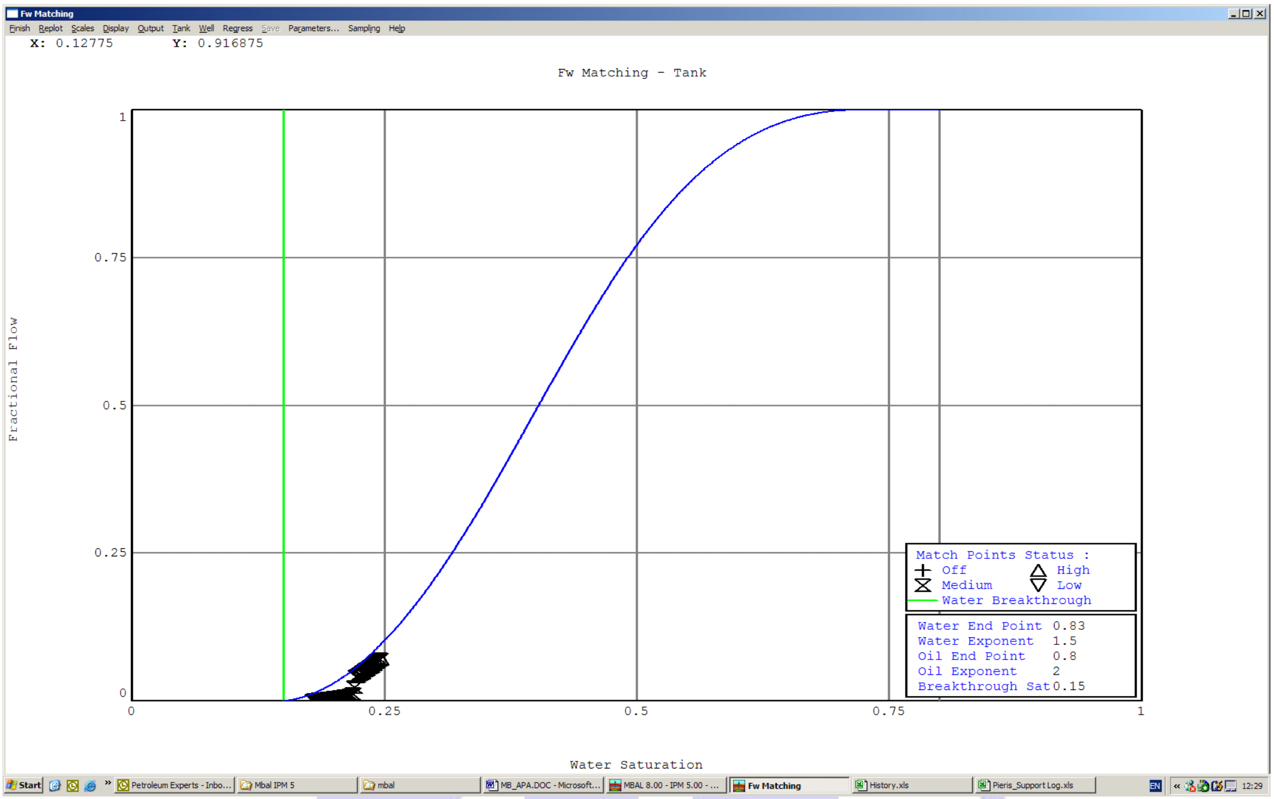

Run History Simulation
Finish Replot Scales Display Output Variables... Help
X: 10/12/1994 Y: 2697.45
Production Simulation
Tank Pressure (psig)
2850
2700
2550
2400
2250
01/03/1987
05/07/1991
08/11/1995
13/03/2000
18/07/2004
Time (date d/m/y)
Tank Pressure
History
Simulation
Start
Petroleum Experts - Inbo...
Mbal IPM 5
mbal
MB_APA.DOC - Microsoft...
MBAL 8.00 - IPM 5.00 - ...
Run History Simulation
History.xls
Pieris_Support Log.xls
EN
12:29

Step 5: Preparing the model for predictions (creating rel perms for each well)

At this stage, the information within the model can be prepared to start running a prediction. This preparation requires the fractional flow of each of the phases to each of the wells to be defined (determine the pseudo relative permeabilities). These are determined by:


MBAL 9.0 - IPM 6.00 - Material Balance - well by well final (solution).mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Add Tank
Add Trans
Add Well
Connect
Move
History Setup
Analytical Method
Graphical Method
Energy Plot
WD function Plot
P/Z vs Gp
Type Curve
All
Sensitivity
Run Simulation
Fw Matching
Fg Matching
Fo Matching
Reports
Well02
Well01
Tank01

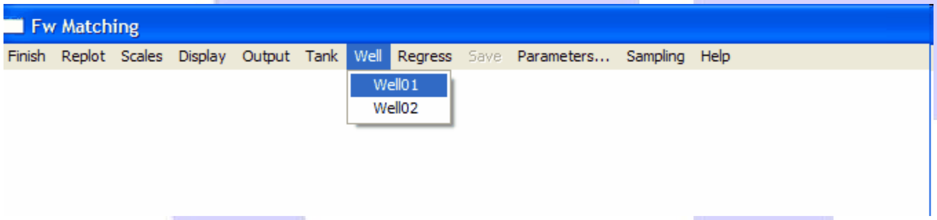
Selecting the 'Fw Matching' option, the program will prompt the fractional flow curve for the *Tank*.

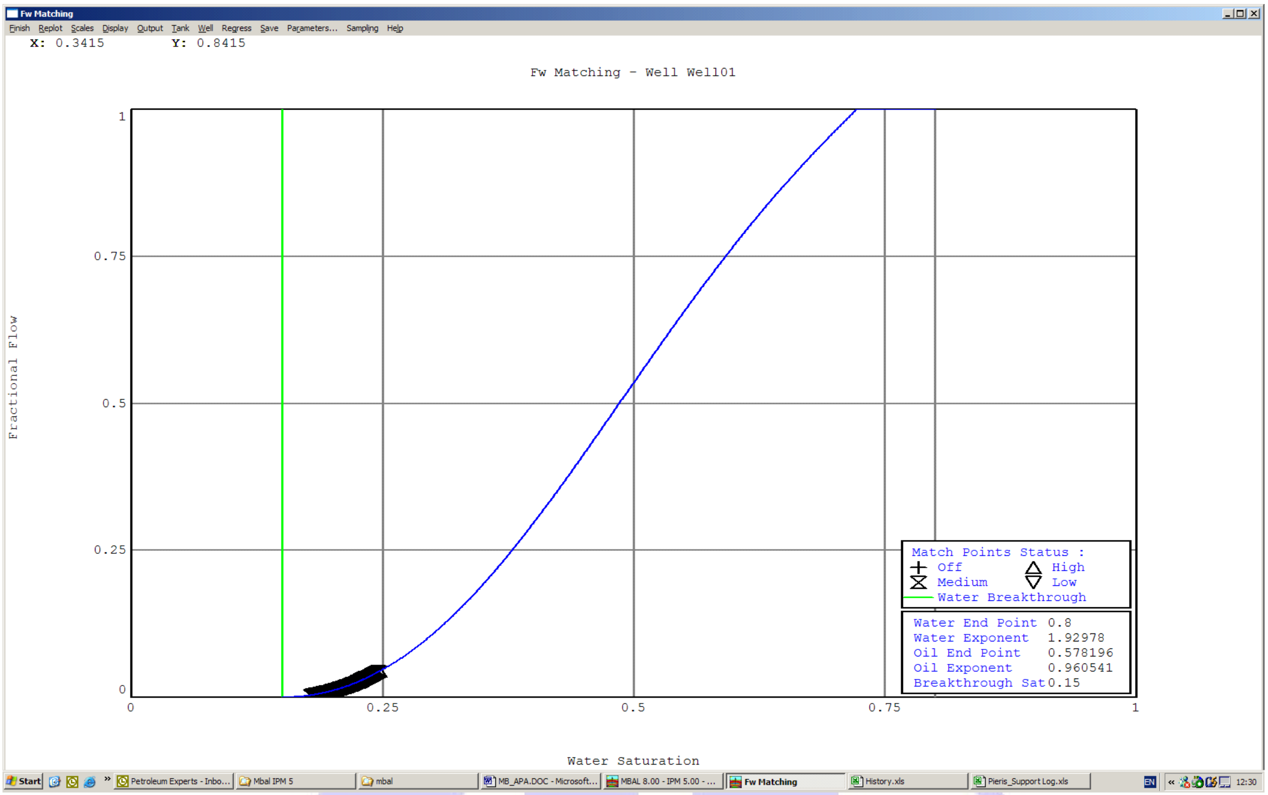


X: 0.12775 Y: 0.916875

Water End Point 0.83
Water Exponent 1.5
Oil End Point 0.8
Oil Exponent 2
Breakthrough Sat 0.15

The fractional flow points shown in the plots are determined from the historical data. The relative permeabilities used when running the predictions must be based on the history for each well. The fractional flow profile for the well can be accessed by clicking on Well | Well 01.

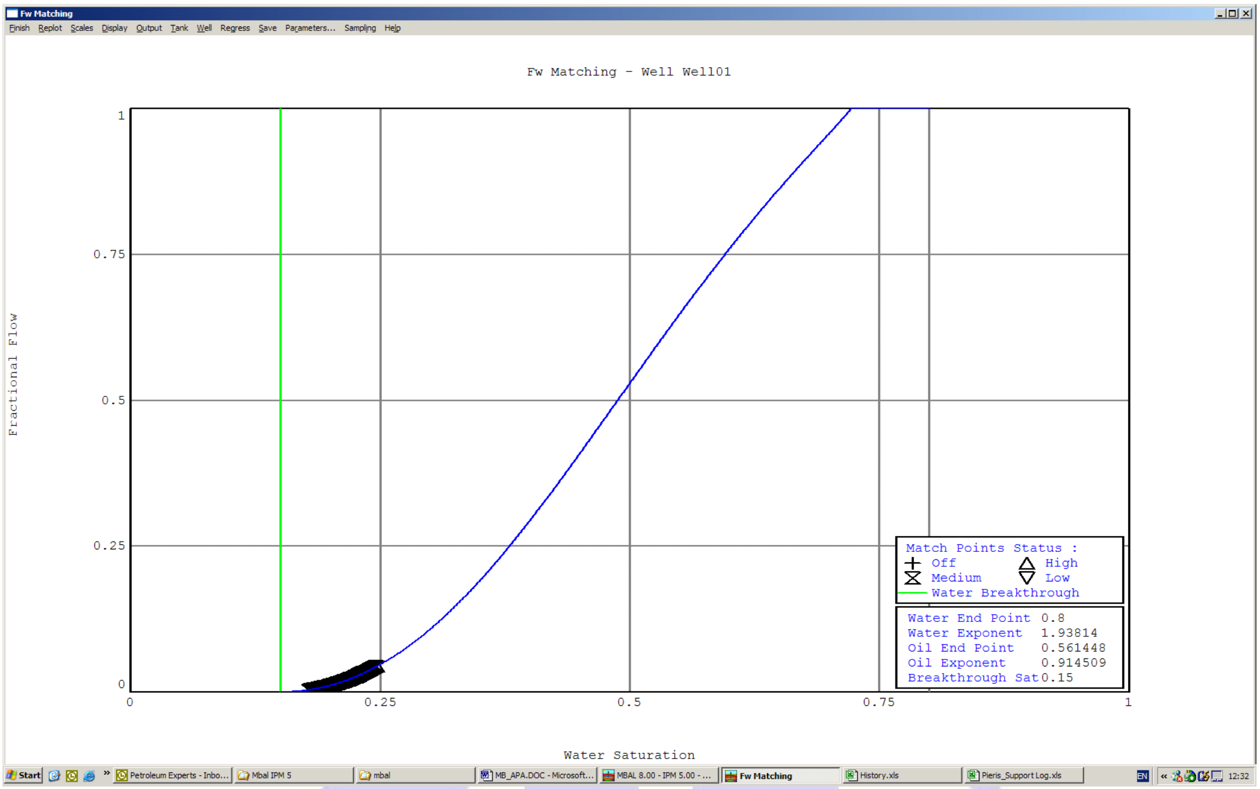

Fw Matching
Finish Replot Scales Display Output Tank Well Regress Save Parameters... Sampling Help
Well01
Well02


Fw Matching
Finish Replot Scales Display Output Tank Well Regress Save Parameters... Sampling Help
Fw Matching - Well Well101
Fractional Flow
1
0.75
0.5
0.25
0
0
0.25
0.5
0.75
1
Water Saturation
Match Points Status :
Off
High
Medium
Low
Water Breakthrough
Start
Petroleum Experts - Inbo...
Mbal IPM 5
mbal
MB_APA.DOC - Microsoft...
MBAL 8.00 - IPM 5.00 - ...
Fw Matching
History.xls
Pieris_Support Log.xls
EN
12:30

X: 0.3415 Y: 0.8415

Water End Point	0.8
Water Exponent	1.92978
Oil End Point	0.578196
Oil Exponent	0.960541
Breakthrough Sat	0.15

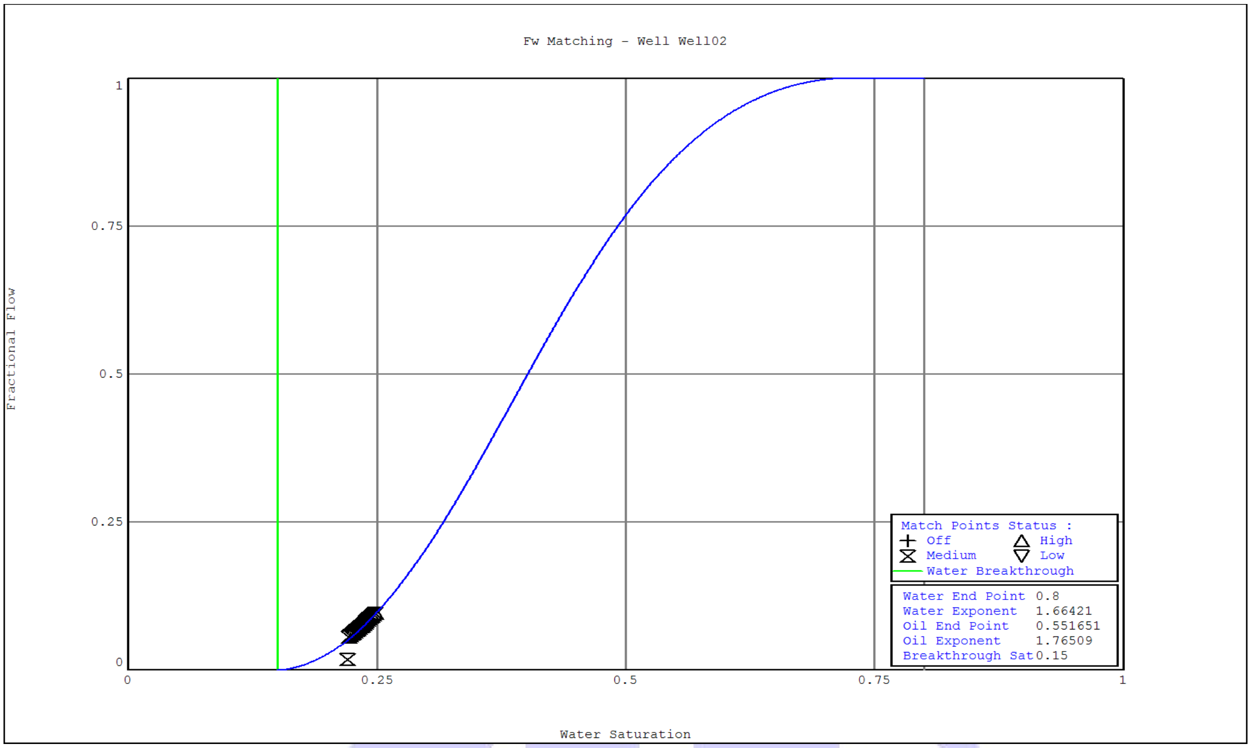
The displayed plot shows the fractional flow profile for Well 01. These can be regressed to match the observed fractional flow points, by using the “Regress” feature:


Fw Matching
Finish Replot Scales Display Output Tank Well Regress Save Parameters... Sampling Help
Fw Matching - Well Well101
Fractional Flow
Water Saturation
1
0.75
0.5
0.25
0
0
0.25
0.5
0.75
1
Match Points Status :
Off
High
Medium
Low
Water Breakthrough
Start
Fw Matching
12:32

Water End Point 0.8
Water Exponent 1.93814
Oil End Point 0.561448
Oil Exponent 0.914509
Breakthrough Sat 0.15

By clicking on the Regress Button, the relative permeability of the fluids for that well are regressed, so that the observed history data can be reproduced. These rel perms can now be used for prediction calculations.

Similarly, the regression must also be performed for Well 2. The fractional flow profile for this well can be accessed by clicking on **Well|Well 02** and then using the Regress feature:

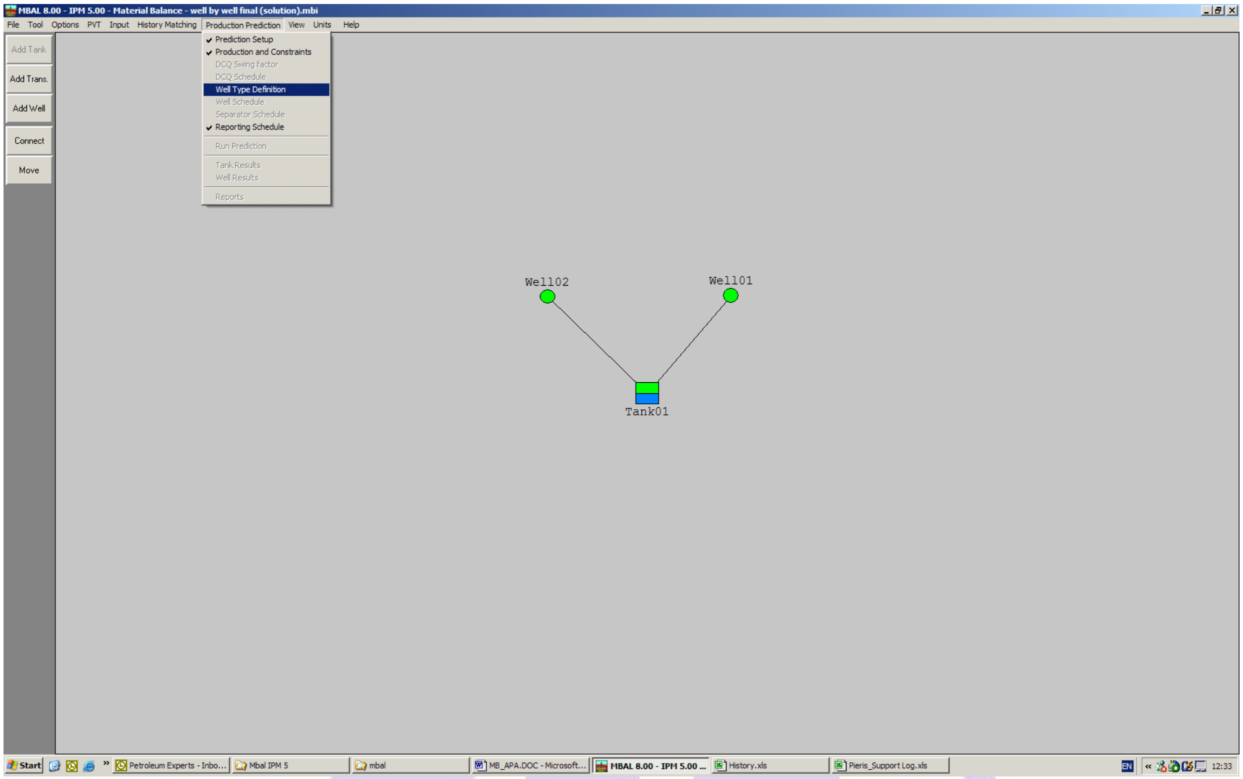


Please note that two sets of rel perms need to be created as history for two wells in the system is available. The procedure required in matching them is the same.

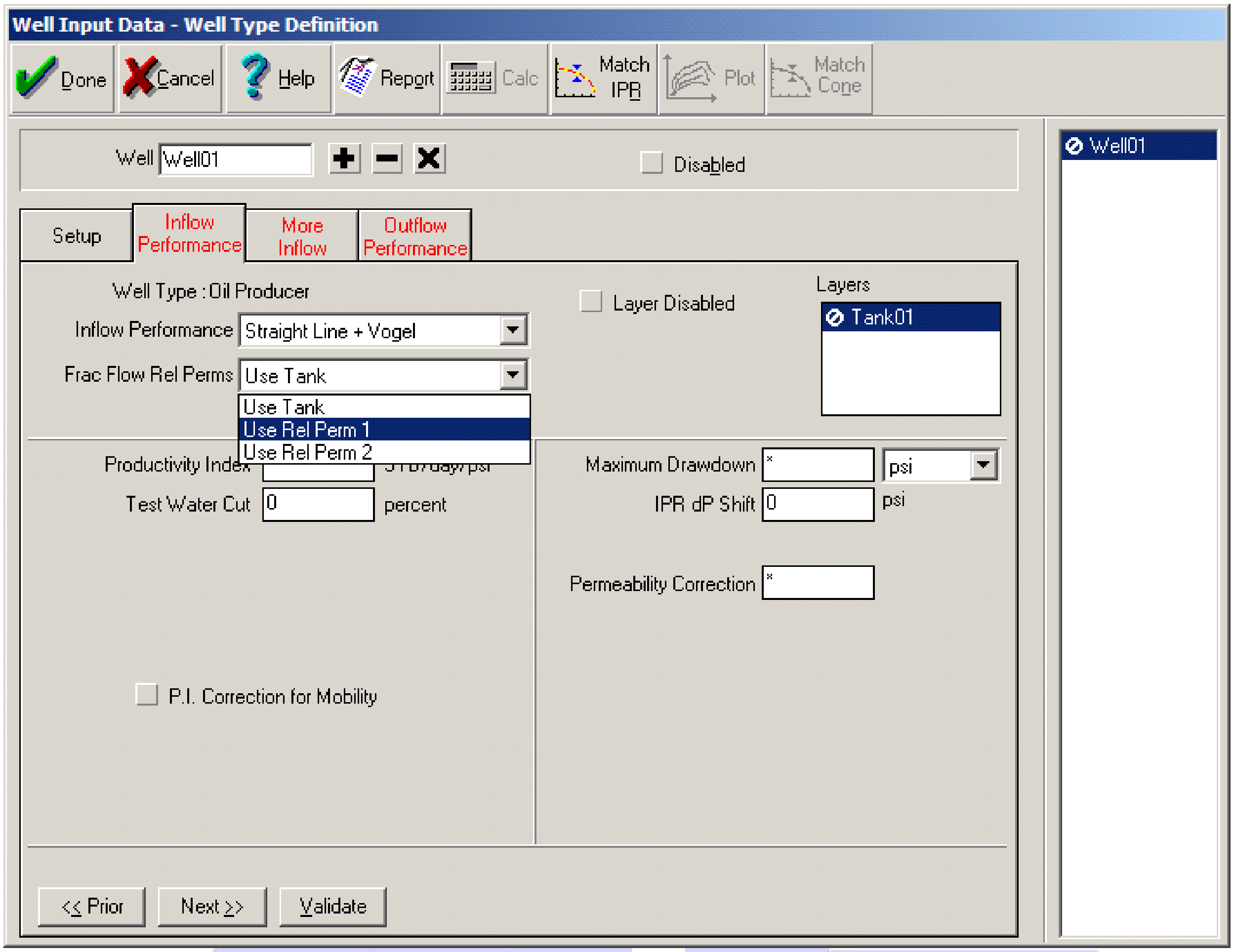
Step 6: Transferring the matched rel perm curves to the prediction wells

In the Quick Start example for **MBAL**, the procedure in creating a prediction well in **MBAL** was explained. The same options will be followed in this section, concentrating more on the options for selecting the matched relative permeability curves to be used for the forecast.

A prediction well can be created under, Production Prediction|Well Type Definition:


MBAL 8.00 - IPM 5.00 - Material Balance - well by well final (solution).mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Prediction Setup
Production and Constraints
DCQ Swing Factor
DCQ Schedule
Well Type Definition
Well Schedule
Separator Schedule
Reporting Schedule
Run Prediction
Tank Results
Well Results
Reports
Add Tank
Add Trans.
Add Well
Connect
Move
Well02
Well01
Tank01

After the + button is selected, along with the type of well, the IPR screen for the prediction well can be invoked:


Well Input Data - Well Type Definition
Done
Cancel
Help
Report
Calc
Match IPR
Plot
Match Cone
Well
Well01
Disabled
Setup
Inflow Performance
More Inflow
Outflow Performance
Layer Disabled
Layers
Tank01
Maximum Drawdown
psi
IPR dP Shift
psi
Permeability Correction
Productivity Index
STB/day/psi
Test Water Cut
percent
P.I. Correction for Mobility
Use Tank
Use Rel Perm 1
Use Rel Perm 2
<< Prior
Next >>
Validate
Well01

Well Type : Oil Producer

Inflow Performance: Straight Line + Vogel

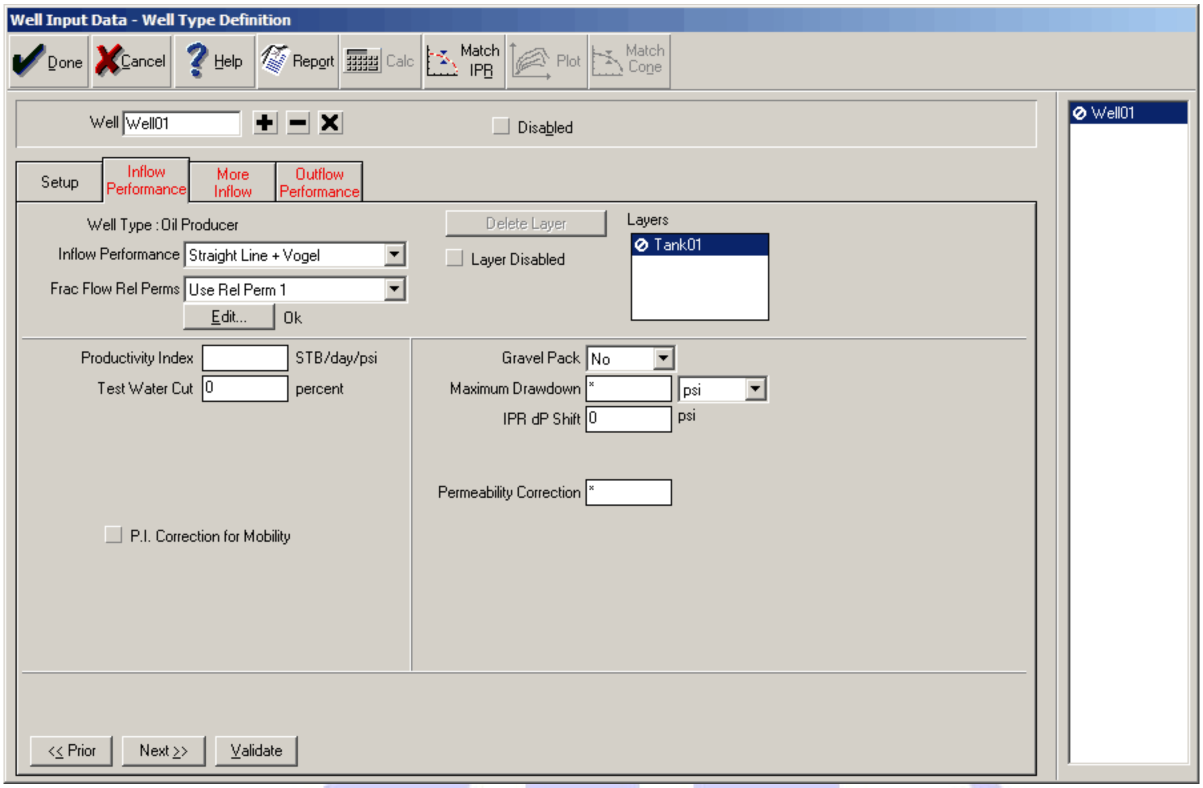
Frac Flow Rel Perms: Use Tank

Test Water Cut: 0 percent

IPR dP Shift: 0 psi

The menu can be dropped down as shown above:

Select one of the two empty sets of rel perms (either Rel perm 1 or 2 will have the same function):


Well Input Data - Well Type Definition
Done
Cancel
Help
Report
Calc
Match IPR
Plot
Match Cone
Disabled
Setup
Inflow Performance
More Inflow
Outflow Performance
Delete Layer
Layer Disabled
Edit...
Ok
Productivity Index
STB/day/psi
P.I. Correction for Mobility
<< Prior
Next >>
Validate

Well Well01

Well Type : Oil Producer

Inflow Performance: Straight Line + Vogel

Frac Flow Rel Perms: Use Rel Perm 1

Test Water Cut 0 percent

Gravel Pack No

Maximum Drawdown * psi

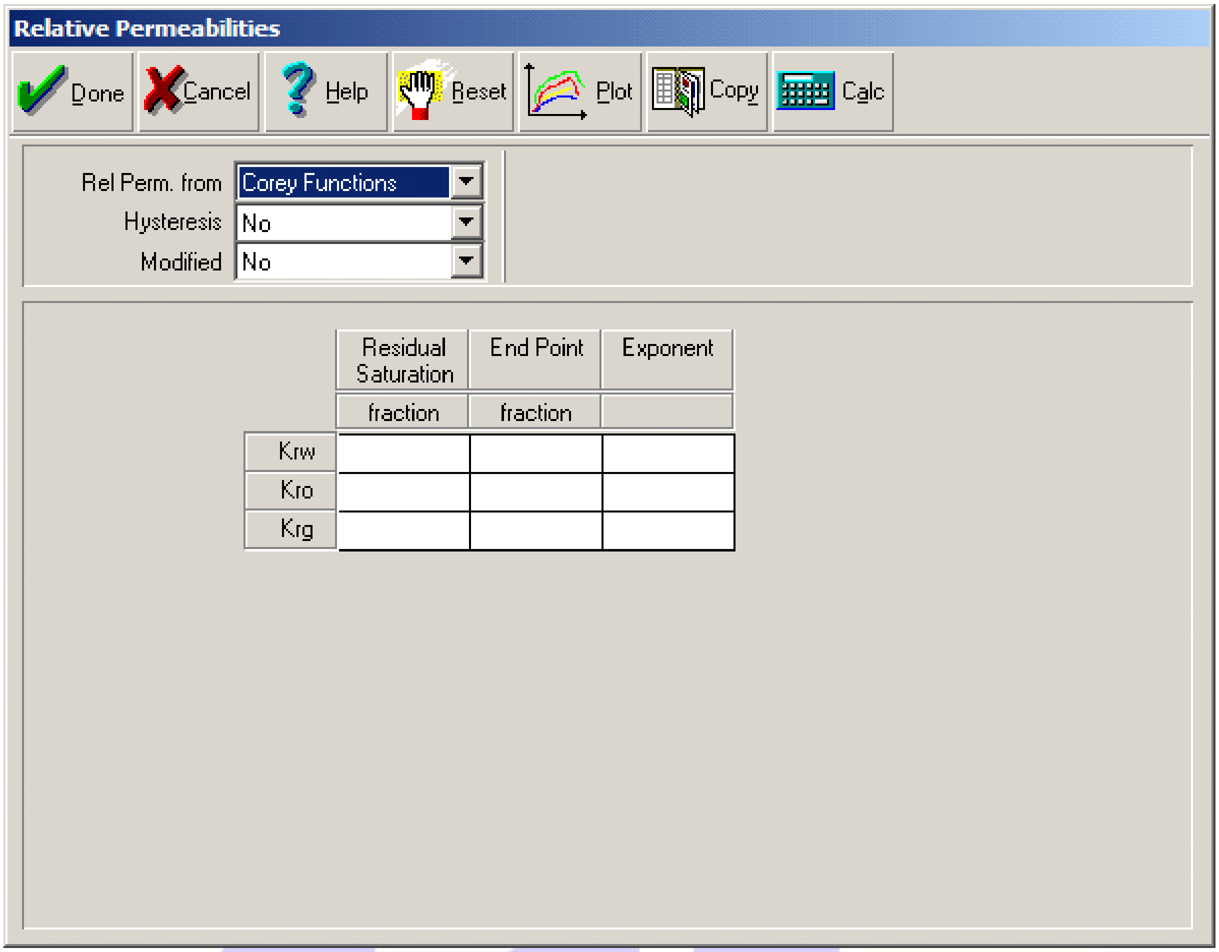
IPR dP Shift 0 psi

Permeability Correction *

Layers: Tank01

Well01

Clicking the "Edit" button, will prompt the screen where the relative permeabilities can be entered:

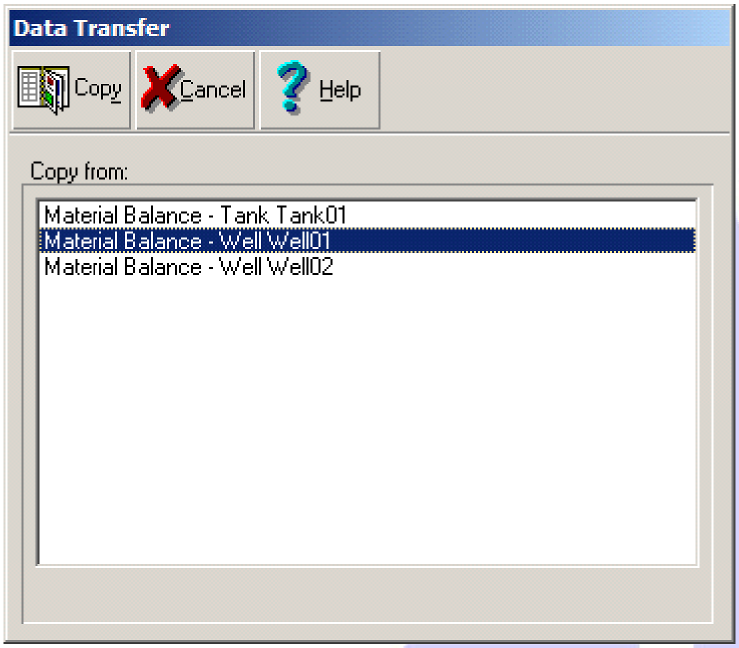

Relative Permeabilities
Done
Cancel
Help
Reset
Plot
Copy
Calc

Rel Perm. from: Corey Functions
Hysteresis: No
Modified: No

	Residual Saturation	End Point	Exponent
	fraction	fraction	
Krw			
Kro			
Krg			

In the screen above, select the “Copy” button. This will show a screen where a list of all of the rel perms that have been matched earlier in the Fw matching feature.

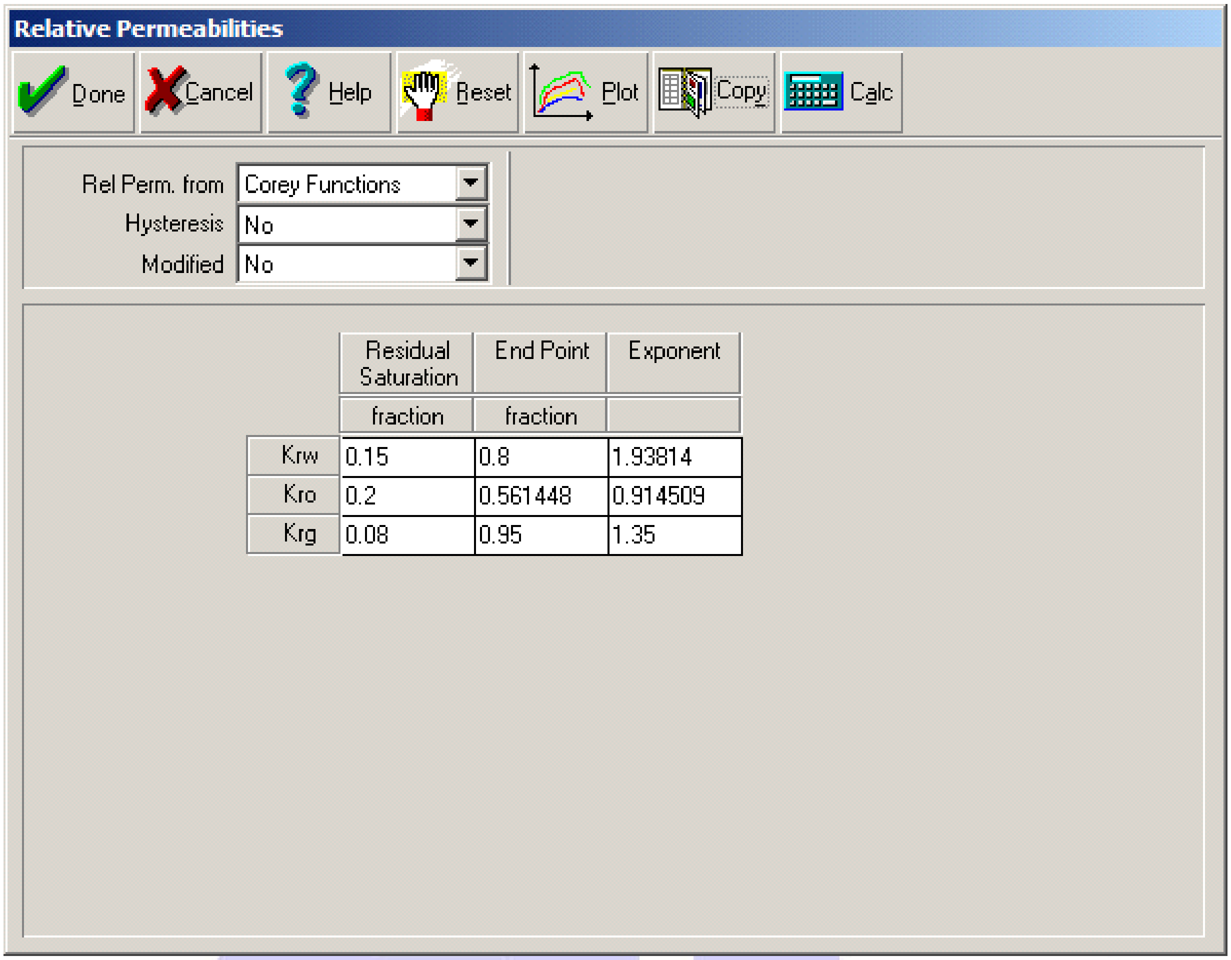
Here, the rel perms corresponding to each particular well can be defined:


Data Transfer
Copy
Cancel
Help

Copy from:

Material Balance - Tank Tank01
Material Balance - Well Well01
Material Balance - Well Well02

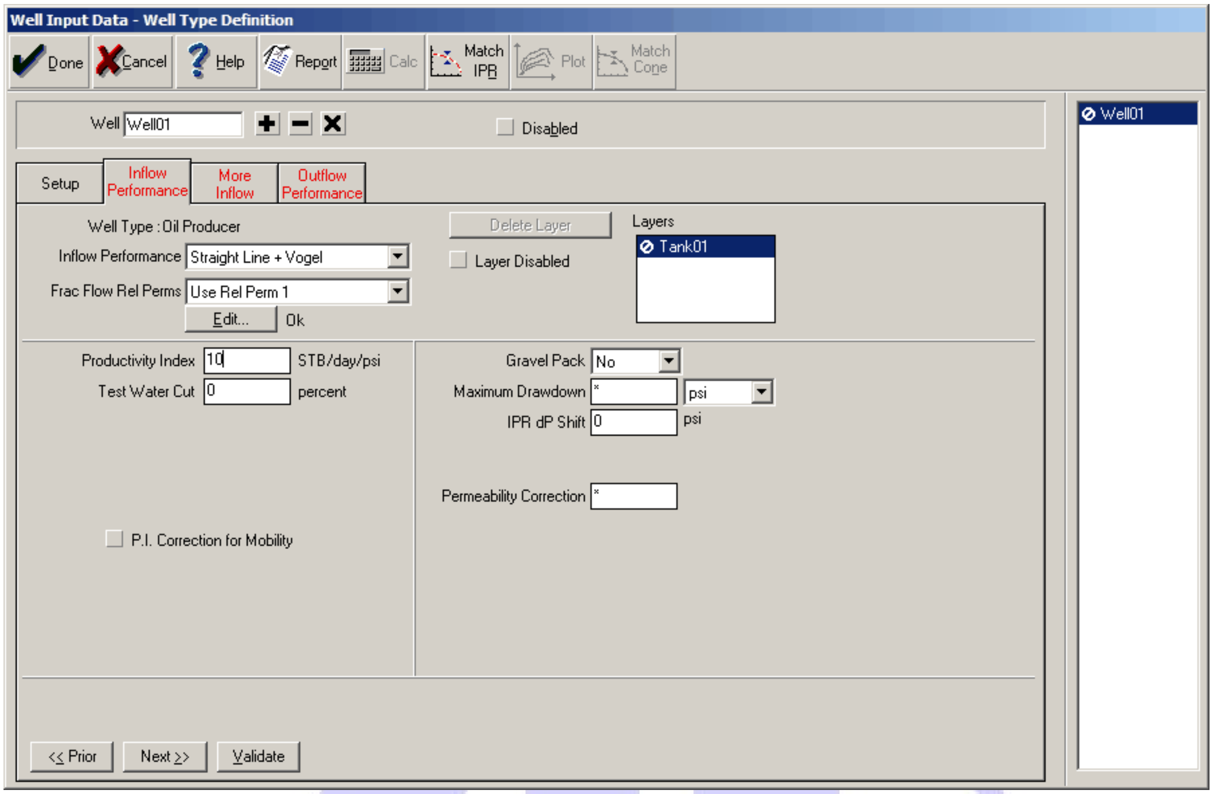
When the “Copy” button is selected, these rel perms will be transferred onto this screen now:


Relative Permeabilities
Done
Cancel
Help
Reset
Plot
Copy
Calc

Rel Perm. from: Corey Functions
Hysteresis: No
Modified: No

	Residual Saturation	End Point	Exponent
	fraction	fraction	
Krw	0.15	0.8	1.93814
Kro	0.2	0.561448	0.914509
Krg	0.08	0.95	1.35

Selecting “Done” will lead back to the well screen, on which the rest of well model options can be completed.


Well Input Data - Well Type Definition
Done
Cancel
Help
Report
Calc
Match IPR
Plot
Match Cone
Setup
Inflow Performance
More Inflow
Outflow Performance
Delete Layer
Edit...
<< Prior
Next >>
Validate

Well Well01

☐ Disabled

Well Type : Oil Producer

Inflow Performance Straight Line + Vogel

Frac Flow Rel Perms Use Rel Perm 1

Ok

☐ Layer Disabled

Layers
Tank01

Productivity Index 10 STB/day/psi

Test Water Cut 0 percent

Gravel Pack No

Maximum Drawdown * psi

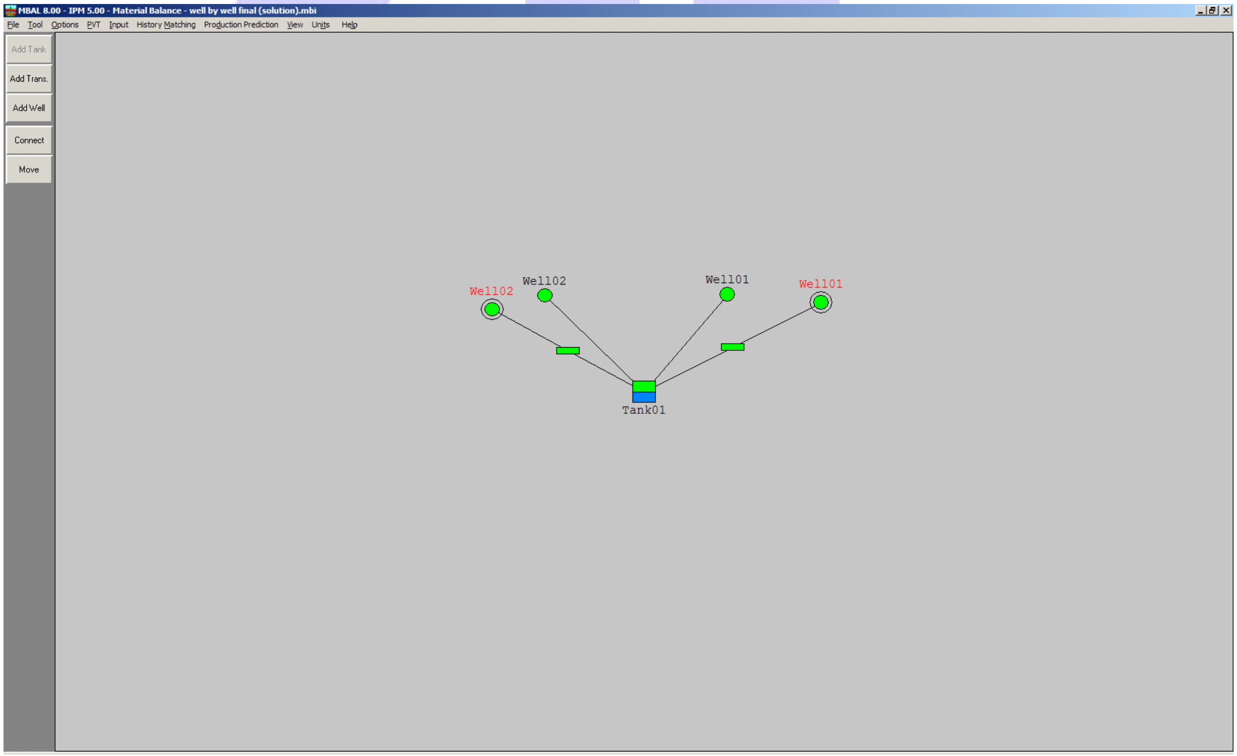
IPR dP Shift 0 psi

Permeability Correction *

☐ P.I. Correction for Mobility

Well01

The same procedure can be used for the second well model now and once this is finished, the model will look like this:


MBAL 8.00 - IPM 5.00 - Material Balance - well by well final (solution).mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Add Tank
Add Trans.
Add Well
Connect
Move
Well02
Well02
Well01
Well01
Tank01

After the rest of the input data is completed, forecasts can be carried out. This procedure will have the added advantage of using different rel perms for every well, so the WC and GOR evolution will reflect the reality of the phase flow into the wells in accordance with their historical production.

3.2.9 Multitank modelling

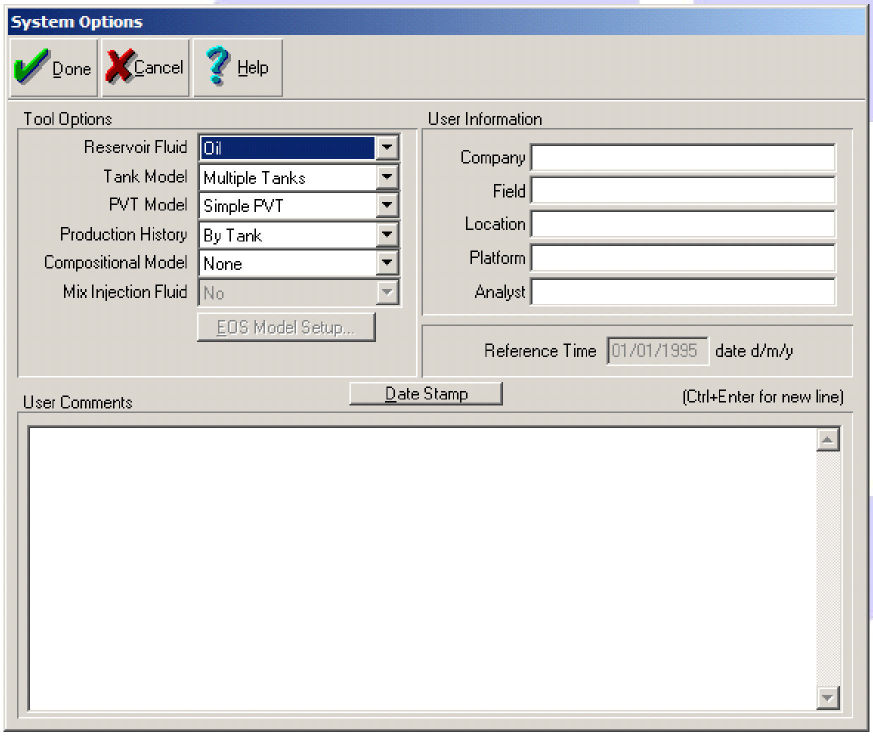
Almost all fields in the world are made up of different compartments, separated by faults that may be closed or open (partially or totally). If the faults are closed, then there is no communication between the tanks and they can be modelled as separate **MBAL tanks**. In the other extreme, if the faults are totally open, then the whole reservoir could be modelled as one **MBAL** reservoir.

However, if the faults separating different compartments are semi-permeable, a transient transfer of fluid from one compartment to the other (governed by the pressure difference between the compartments) will occur. **MBAL** has an advanced feature in which the user can create multitank models with time dependent transmissibility between the tanks, allowing the modelling of these complex reservoirs to be carried out.

For this example, the **MBAL** starting model is provided under the **MBAL** samples, in the "Multitank example" directory. Please open the **MBAL** file called "Multitank Starting Point.mbi"

Step 1: Initialising the model

The Multi-tank feature can be activated from the options menu:

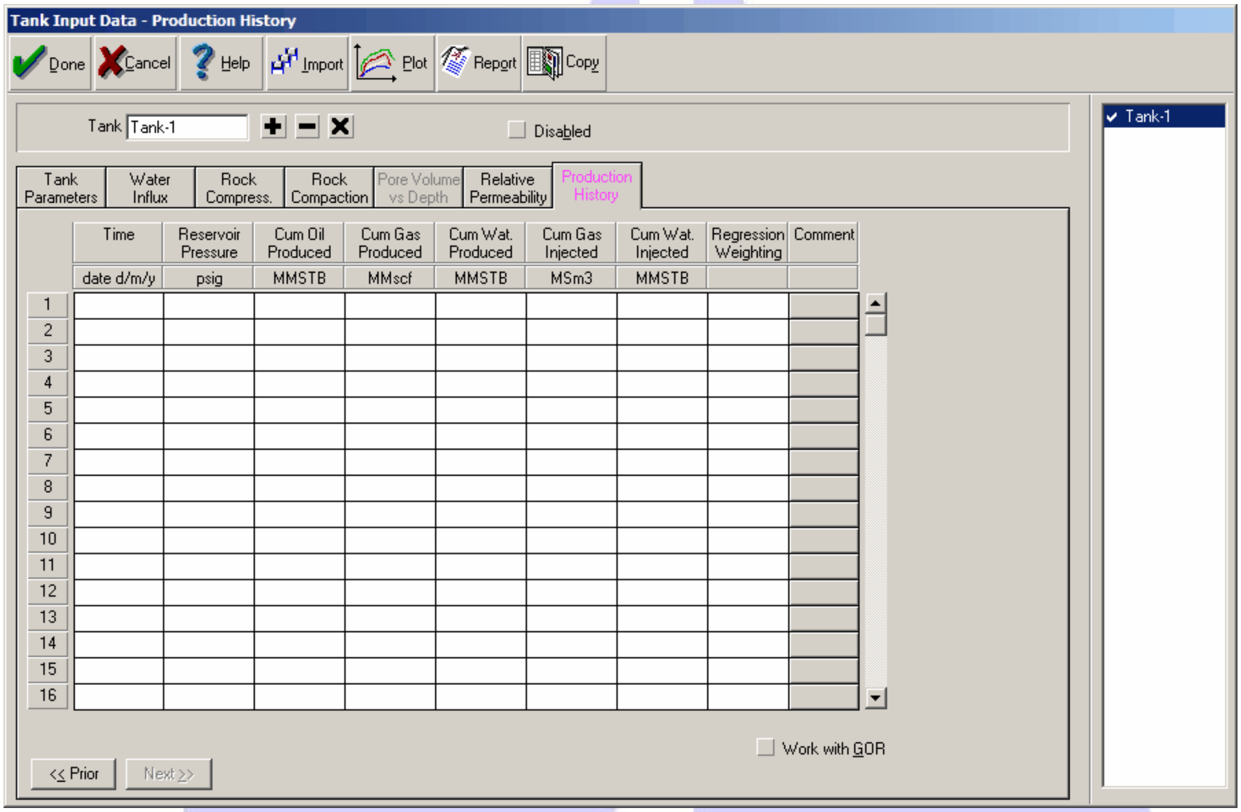


Reservoir Fluid: Oil
Tank Model: Multiple Tanks
PVT Model: Simple PVT
Production History: By Tank
Compositional Model: None
Mix Injection Fluid: No

Company:
Field:
Location:
Platform:
Analyst:

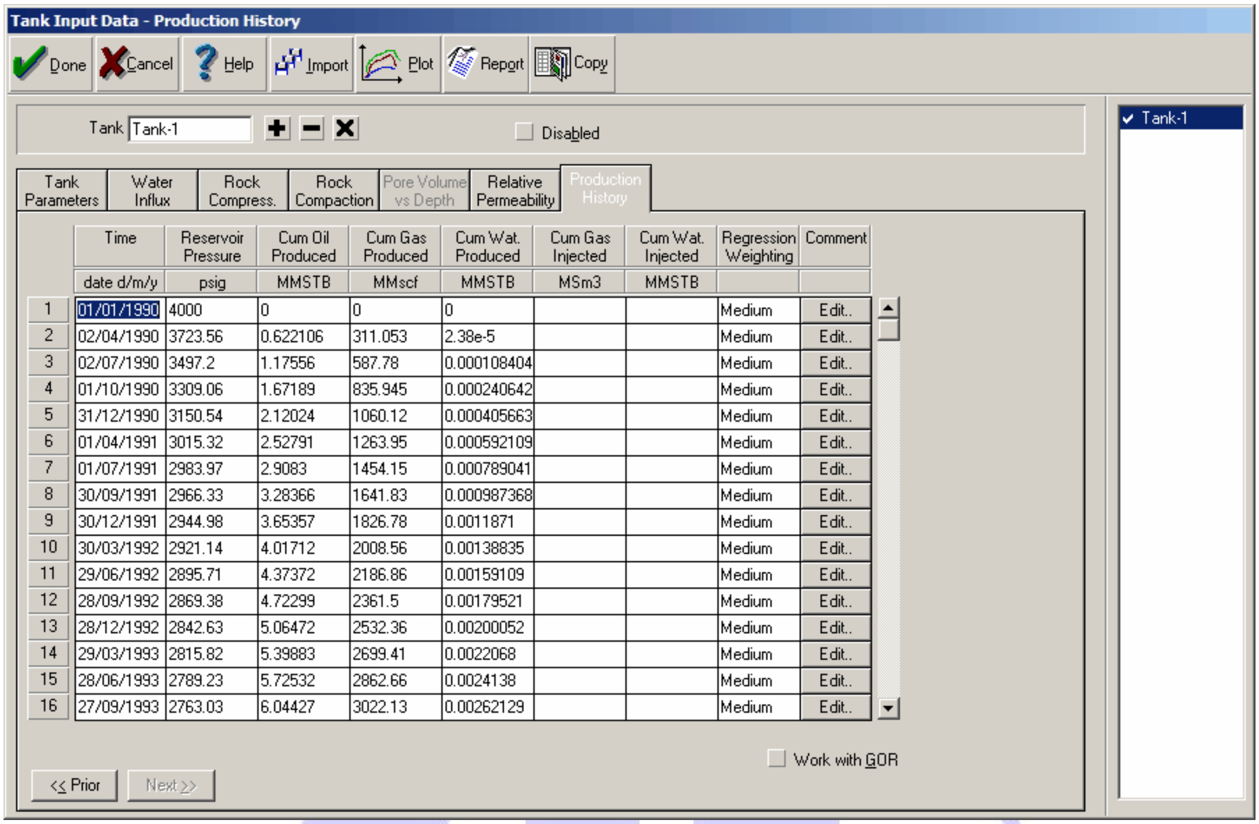
Reference Time: 01/01/1995 date d/m/y

All of the relevant data can be entered as per previous examples. Most of the data has already been already entered for convenience. The data for the production history is missing, as can be seen from the screen below:


Tank Input Data - Production History
Done
Cancel
Help
Import
Plot
Report
Copy
Tank
Tank-1
Disabled
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
Work with GOR
<< Prior
Next >>
Tank-1

	Time	Reservoir Pressure	Cum Oil Produced	Cum Gas Produced	Cum Wat. Produced	Cum Gas Injected	Cum Wat. Injected	Regression Weighting	Comment
	date d/m/y	psig	MMSTB	MMscf	MMSTB	MSm3	MMSTB		
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									

The production history can be copied here from the Excel file present in the same directory as above.


Tank Input Data - Production History
Done
Cancel
Help
Import
Plot
Report
Copy
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
<< Prior
Next >>
Tank-1

Tank Tank-1

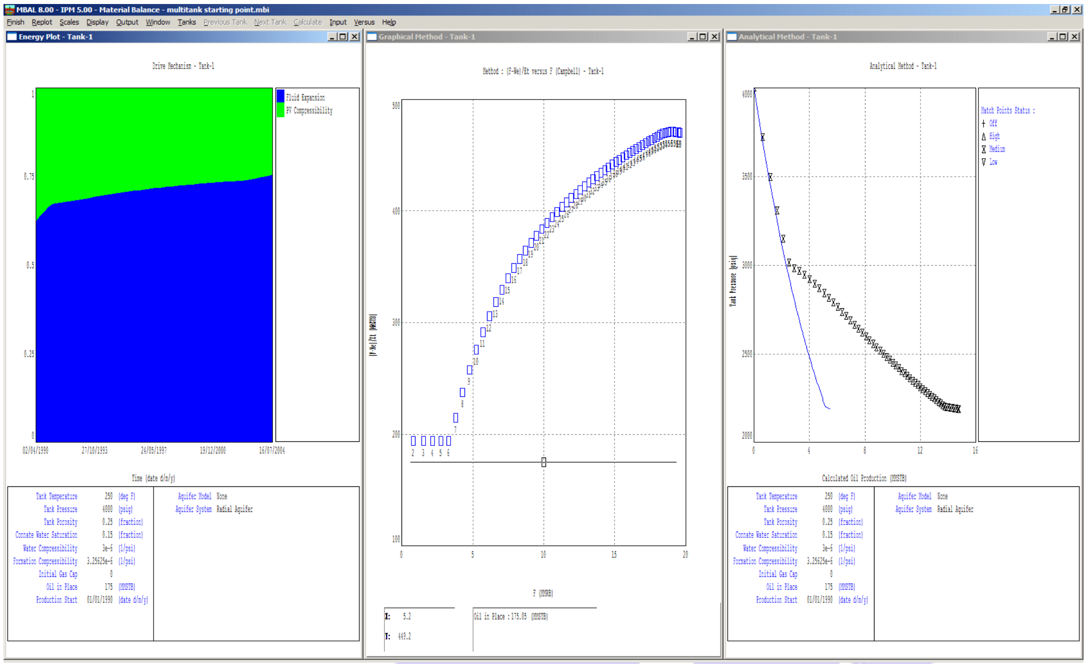
☐ Disabled

	Time	Reservoir Pressure	Cum Oil Produced	Cum Gas Produced	Cum Wat. Produced	Cum Gas Injected	Cum Wat. Injected	Regression Weighting	Comment
	date d/m/y	psig	MMSTB	MMscf	MMSTB	MSm3	MMSTB		
1	01/01/1990	4000	0	0	0			Medium	Edit..
2	02/04/1990	3723.56	0.622106	311.053	2.38e-5			Medium	Edit..
3	02/07/1990	3497.2	1.17556	587.78	0.000108404			Medium	Edit..
4	01/10/1990	3309.06	1.67189	835.945	0.000240642			Medium	Edit..
5	31/12/1990	3150.54	2.12024	1060.12	0.000405663			Medium	Edit..
6	01/04/1991	3015.32	2.52791	1263.95	0.000592109			Medium	Edit..
7	01/07/1991	2983.97	2.9083	1454.15	0.000789041			Medium	Edit..
8	30/09/1991	2966.33	3.28366	1641.83	0.000987368			Medium	Edit..
9	30/12/1991	2944.98	3.65357	1826.78	0.0011871			Medium	Edit..
10	30/03/1992	2921.14	4.01712	2008.56	0.00138835			Medium	Edit..
11	29/06/1992	2895.71	4.37372	2186.86	0.00159109			Medium	Edit..
12	28/09/1992	2869.38	4.72299	2361.5	0.00179521			Medium	Edit..
13	28/12/1992	2842.63	5.06472	2532.36	0.00200052			Medium	Edit..
14	29/03/1993	2815.82	5.39883	2699.41	0.0022068			Medium	Edit..
15	28/06/1993	2789.23	5.72532	2862.66	0.0024138			Medium	Edit..
16	27/09/1993	2763.03	6.04427	3022.13	0.00262129			Medium	Edit..

☐ Work with GOR

Step 2: Focusing on the First Reservoir

Under “History Matching/All” all of the history plots can be seen as normal.


MBAL 8.00 - IPM 5.00 - Material Balance - multitank starting point.mbi
Finish Replot Scales Display Output Window Tanks Previous Tank Next Tank Calculate Input Versus Help
Energy Plot - Tank-1
Drive Mechanism - Tank-1
Fluid Expansion
PV Compressibility
1
0.75
0.5
0.25
0
02/04/1990
27/10/1993
24/05/1997
19/12/2000
16/07/2004
Time (date d/m/y)
Graphical Method - Tank-1
Method : (F-We)/Et versus F (Campbell) - Tank-1
500
400
300
200
100
0
5
10
15
20
F (MMRB)
Analytical Method - Tank-1
Analytical Method - Tank-1
Match Points Status :
Off
High
Medium
Low
Tank Pressure (psig)
4000
3500
3000
2500
2000
0
4
8
12
16
Calculated Oil Production (MMSTB)

Tank Temperature 250 (deg F)
Tank Pressure 4000 (psig)
Tank Porosity 0.25 (fraction)
Connate Water Saturation 0.15 (fraction)
Water Compressibility 3e-6 (1/psi)
Formation Compressibility 3.25625e-6 (1/psi)
Initial Gas Cap 0
Oil in Place 175 (MMSTB)
Production Start 01/01/1990 (date d/m/y)

Aquifer Model None
Aquifer System Radial Aquifer

X: 5.2
Y: 449.2

Oil in Place : 175.05 (MMSTB)

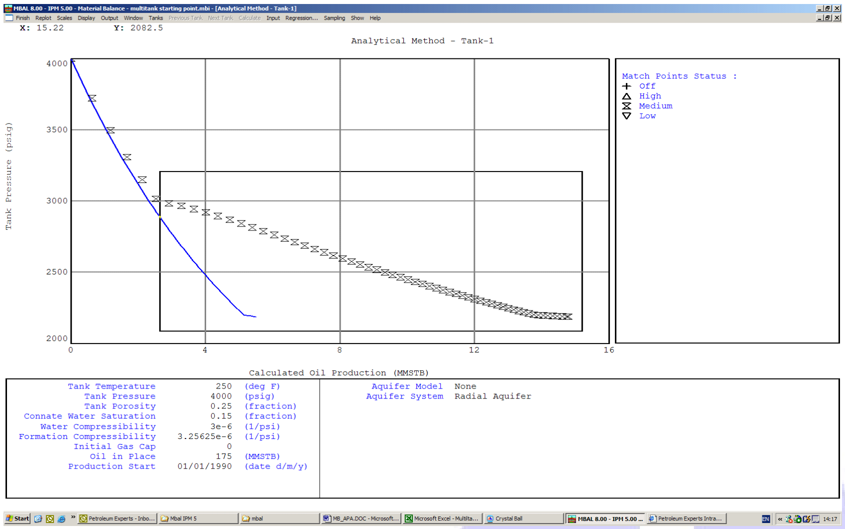
Tank Temperature 250 (deg F)
Tank Pressure 4000 (psig)
Tank Porosity 0.25 (fraction)
Connate Water Saturation 0.15 (fraction)
Water Compressibility 3e-6 (1/psi)
Formation Compressibility 3.25625e-6 (1/psi)
Initial Gas Cap 0
Oil in Place 175 (MMSTB)
Production Start 01/01/1990 (date d/m/y)

Aquifer Model None
Aquifer System Radial Aquifer

The Campbell plot shows the energy given by the reservoir (flat line initially) and then there is an increasing trend to the data. This signifies that initially the reservoir does not see any energy from outside sources, however, at some point there is energy coming from somewhere. This energy would not be due to aquifer drive as it would show from day 1, so we conclude that a fault has been broken and a second reservoir is supporting the first.

In history matching this situation, we will first concentrate on the period where the first reservoir is acting alone. Having matched the parameters of the first reservoir, the second reservoir can then be matched, focussing more on the later period of production.

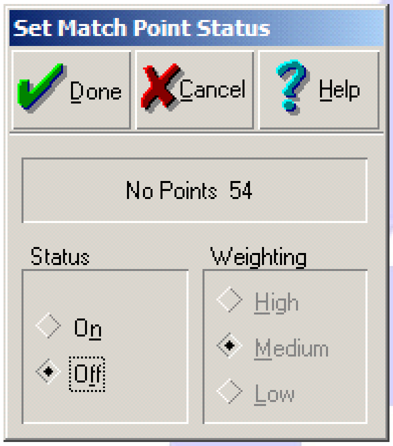
In the Analytical plot in **MBAL**, the history points can be manipulated by **dragging with the right mouse button** and creating an area with the points to be selected, as shown below:


MBAL 8.00 - IPM 5.00 - Material Balance - multitank starting point.mbi - [Analytical Method - Tank-1]
Finish Replot Scales Display Output Window Tanks Previous Tank Next Tank Calculate Input Regression... Sampling Show Help
X: 15.22 Y: 2082.5
Analytical Method - Tank-1
Tank Pressure (psig)
4000
3500
3000
2500
2000
0
4
8
12
16
Calculated Oil Production (MMSTB)
Match Points Status :
+ Off
△ High
⧖ Medium
▽ Low
Start
Petroleum Experts - Inbo...
Mbal IPM 5
mbal
MB_APA.DOC - Microsoft...
Microsoft Excel - Multita...
Crystal Ball
MBAL 8.00 - IPM 5.00 ...
Petroleum Experts Intra...
14:17

Tank Temperature	250	(deg F)
Tank Pressure	4000	(psig)
Tank Porosity	0.25	(fraction)
Connate Water Saturation	0.15	(fraction)
Water Compressibility	3e-6	(1/psi)
Formation Compressibility	3.25625e-6	(1/psi)
Initial Gas Cap	0	
Oil in Place	175	(MMSTB)
Production Start	01/01/1990	(date d/m/y)

Aquifer Model None
Aquifer System Radial Aquifer

When the mouse button is released, the following screen will appear:

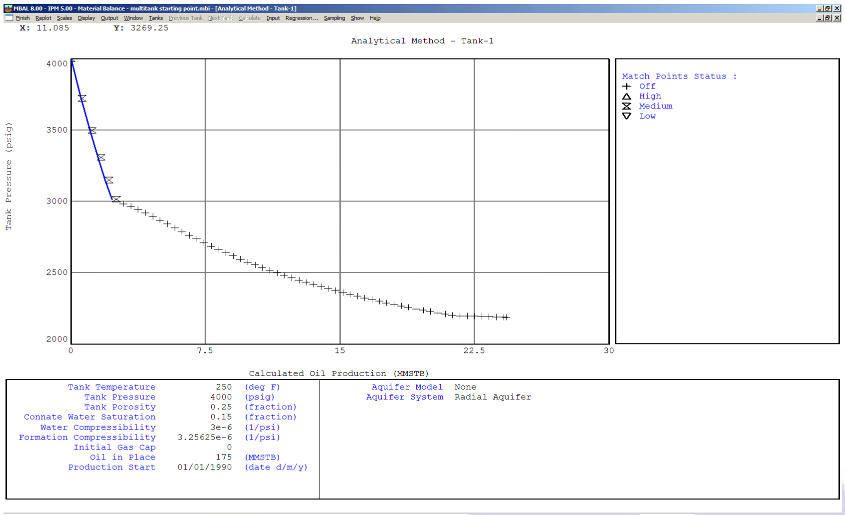

Set Match Point Status
Done
Cancel
Help

No Points 54

Status
○ On
● Off

Weighting
○ High
● Medium
○ Low

The points can now be set to “Off”. The Analytical method will look like this:


MBAL 8.00 - IPM 5.00 - Material Balance - multitank starting point.mbi - [Analytical Method - Tank-1]
Finish Replot Scales Display Output Window Tanks Previous Tank Next Tank Calculate Input Regression... Sampling Show Help
X: 11.085
Y: 3269.25
Analytical Method - Tank-1
Tank Pressure (psig)
4000
3500
3000
2500
2000
0
7.5
15
22.5
30
Calculated Oil Production (MMSTB)
Match Points Status :
+ Off
△ High
⧖ Medium
▽ Low

Tank Temperature	250	(deg F)
Tank Pressure	4000	(psig)
Tank Porosity	0.25	(fraction)
Connate Water Saturation	0.15	(fraction)
Water Compressibility	3e-6	(1/psi)
Formation Compressibility	3.25625e-6	(1/psi)
Initial Gas Cap	0	
Oil in Place	175	(MMSTB)
Production Start	01/01/1990	(date d/m/y)

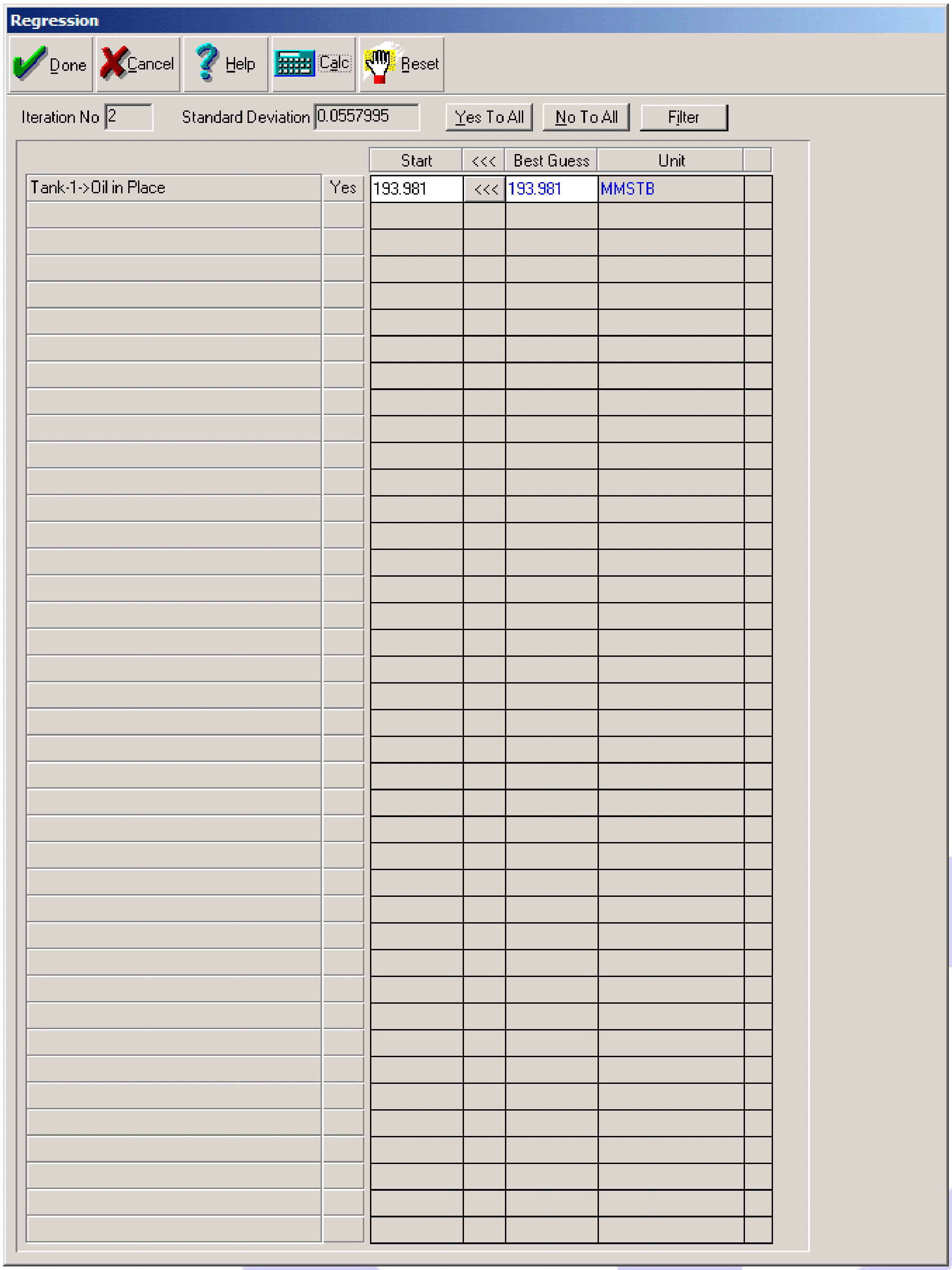
Aquifer Model None
Aquifer System Radial Aquifer

Please note that for changes to take place, the model needs to be re-calculated by selecting the "Calculate" button on the Analytical method plot.

The history match being carried out would now refer to the production from the first reservoir before any external support was experienced.

Step 3: Matching first reservoir parameters

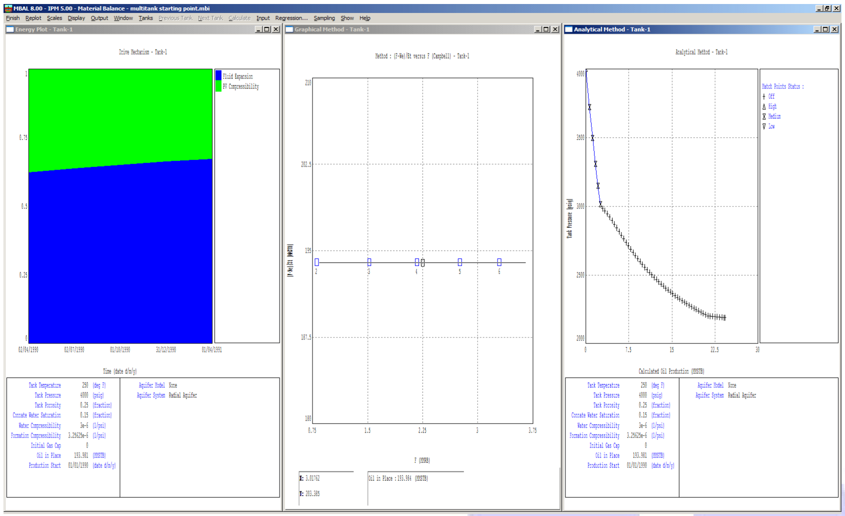
Selecting the Regression Option


Regression
Done
Cancel
Help
Calc
Reset
Yes To All
No To All
Filter

Iteration No 2
Standard Deviation 0.0557995

		Start	<<<	Best Guess	Unit
Tank-1->Oil in Place	Yes	193.981	<<<	193.981	MMSTB

The original Oil in place is set as a regression parameter and once the calculations are finished, the history matching plots will look like this:


MBAL 8.00 - IPM 5.00 - Material Balance - multitank starting point.mbi
Energy Plot - Tank-1
Drive Mechanism - Tank-1
Fluid Expansion
PV Compressibility
Time (date d/m/y)
Graphical Method - Tank-1
Method : (F-We)/Et versus F (Campbell) - Tank-1
F (MMRB)
Analytical Method - Tank-1
Match Points Status :
Off
High
Medium
Low
Tank Pressure (psig)
Calculated Oil Production (MMSTB)

Tank Temperature 250 (deg F)
Tank Pressure 4000 (psig)
Tank Porosity 0.25 (fraction)
Connate Water Saturation 0.15 (fraction)
Water Compressibility 3e-6 (1/psi)
Formation Compressibility 3.25625e-6 (1/psi)
Initial Gas Cap 0
Oil in Place 193.981 (MMSTB)
Production Start 01/01/1990 (date d/m/y)

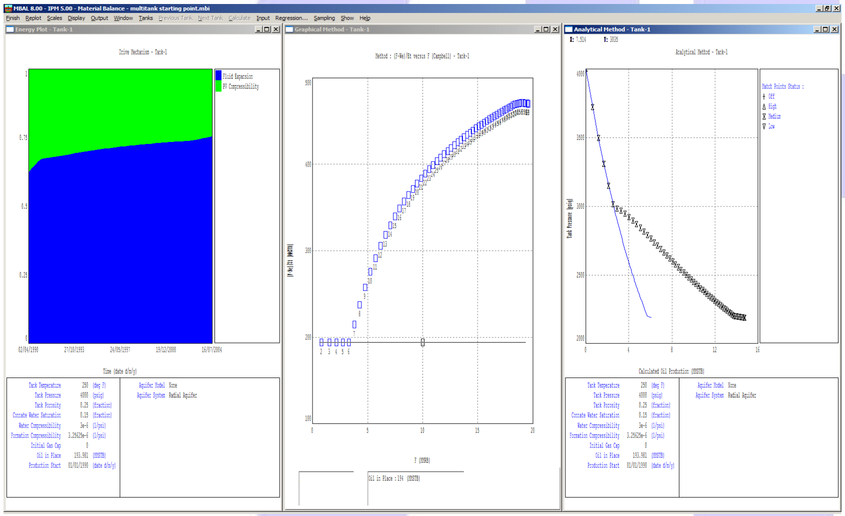
Aquifer Model None
Aquifer System Radial Aquifer

X: 3.01762
Y: 203.385
Oil in Place : 193.984 (MMSTB)

The Campbell plot is now a straight line and the model can reproduce the data which was matched in the analytical method.

Step 4: Activating region where both reservoirs are seen on production data

For this step, the rest of the data needs to be activated. The activation of data points requires the same method which was undertaken to de-activate them **(use the right mouse button)**.


MBAL 8.00 - IPM 5.00 - Material Balance - multitank starting point.mbi
Energy Plot - Tank-1
Drive Mechanism - Tank-1
Fluid Expansion
PV Compressibility
Time (date d/m/y)
Graphical Method - Tank-1
Method : (F-We)/Et versus F (Campbell) - Tank-1
F (MMRB)
Analytical Method - Tank-1
Match Points Status :
Off
High
Medium
Low
Tank Pressure (psig)
Calculated Oil Production (MMSTB)

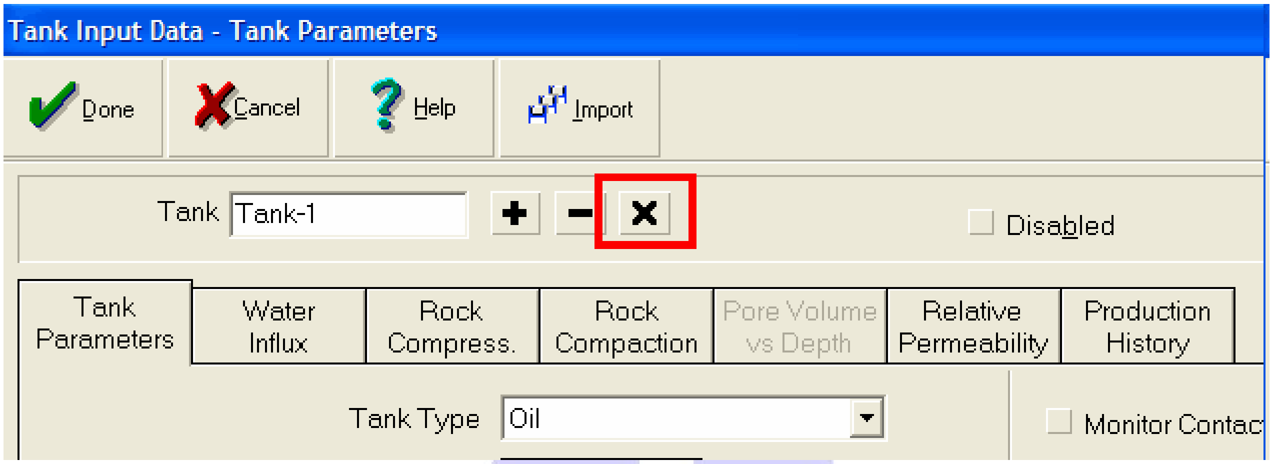
X: 7.514 Y: 3035

Tank Temperature 250 (deg F)
Tank Pressure 4000 (psig)
Tank Porosity 0.25 (fraction)
Connate Water Saturation 0.15 (fraction)
Water Compressibility 3e-6 (1/psi)
Formation Compressibility 3.25625e-6 (1/psi)
Initial Gas Cap 0
Oil in Place 193.981 (MMSTB)
Production Start 01/01/1990 (date d/m/y)

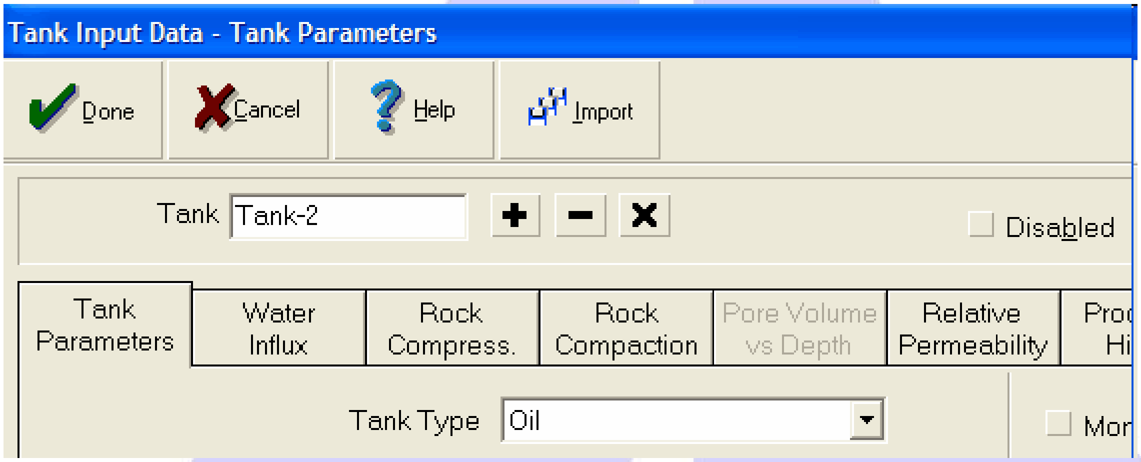
Aquifer Model None
Aquifer System Radial Aquifer

Oil in Place : 194 (MMSTB)

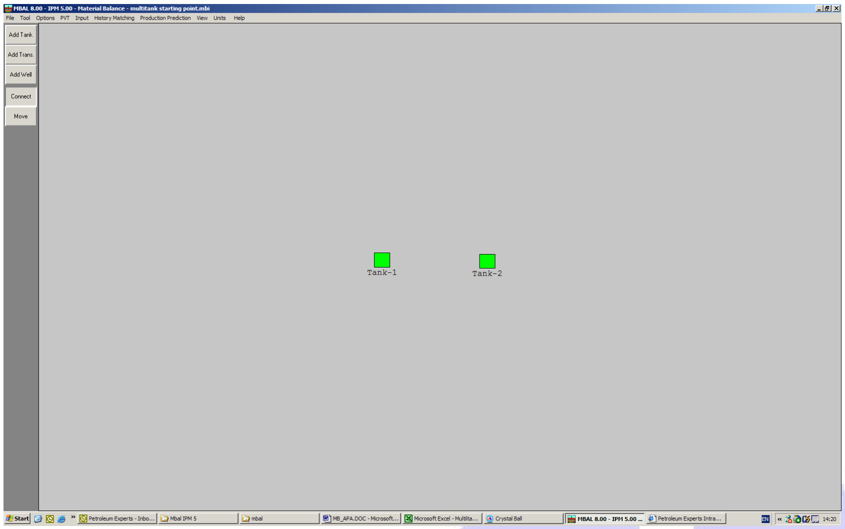
In order to match the later response in the production data, a second reservoir will be created and connected to the first one. Initially, a copy of the first reservoir is created by selecting the X button on the Tank Input Data as shown below:


Tank Input Data - Tank Parameters
Done
Cancel
Help
Import
Tank
Tank-1
Disabled
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
Tank Type
Oil
Monitor Contac

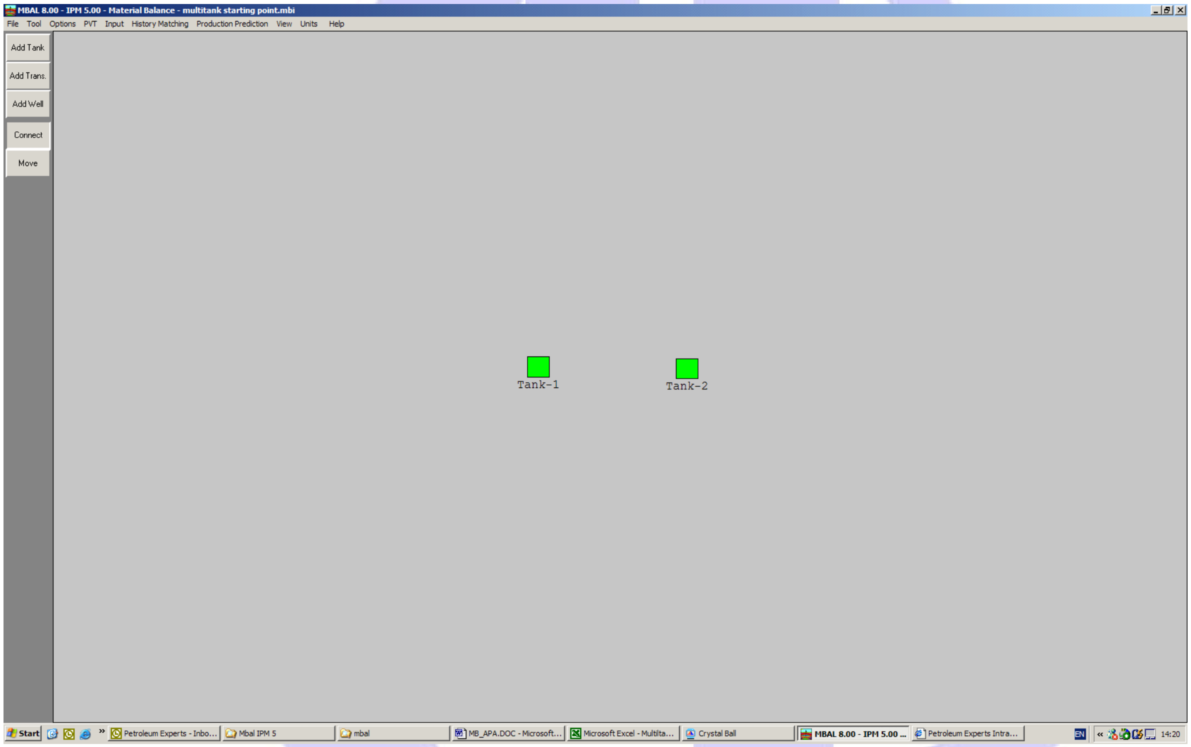
A new Tank will be created which will be renamed this file as Tank-2 and click on 'Done.'


Tank Input Data - Tank Parameters
Done
Cancel
Help
Import
Tank
Tank-2
Disabled
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Proc Hi
Tank Type
Oil
Mor

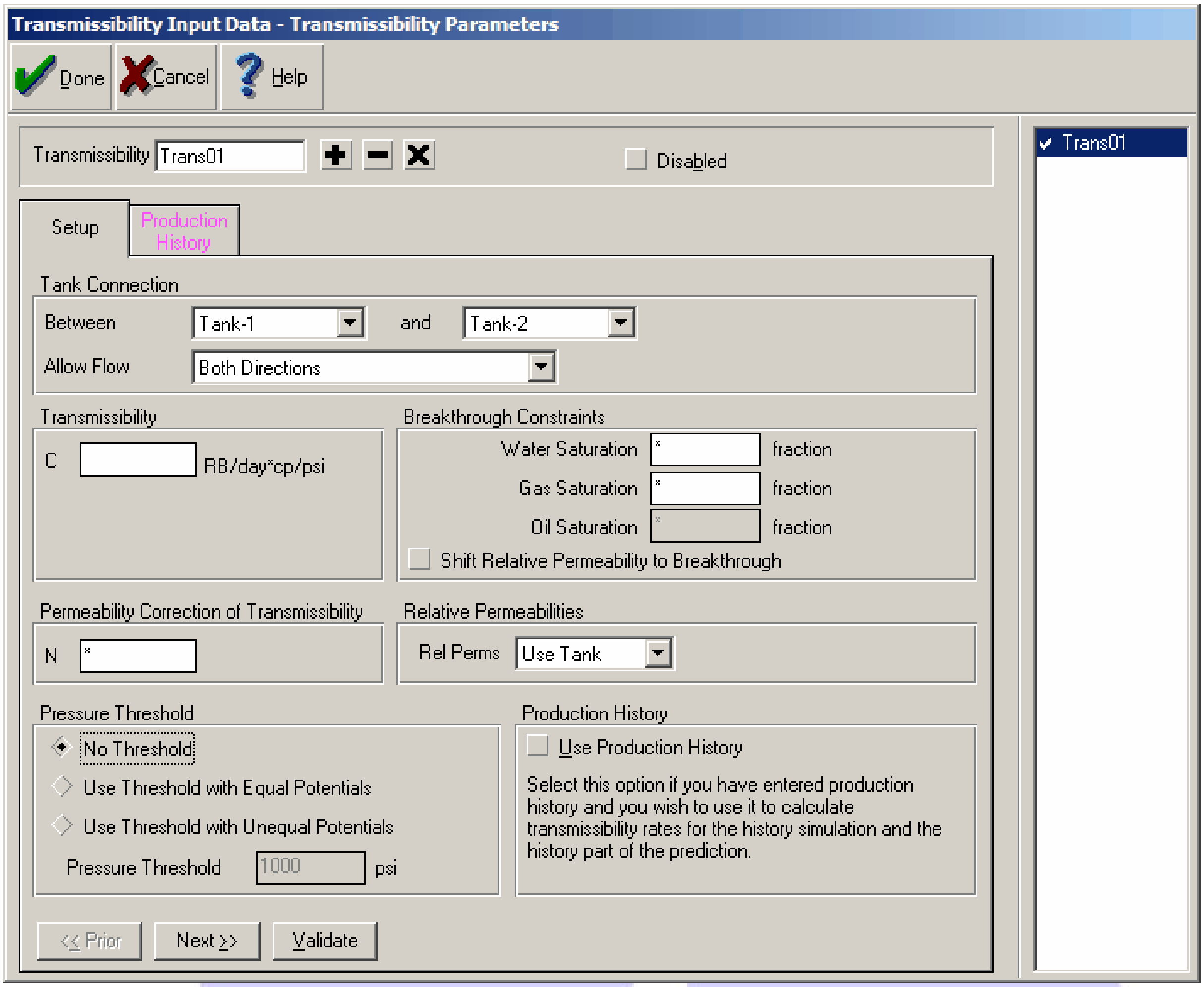
As soon as this is done, the second reservoir will appear on the main screen of **MBAL**: The tanks can then be moved on the main screen by clicking on the MOVE button to the left of the screen, and selecting the tank to be moved by clicking on it and dragging on it.


MBAL 8.00 - IPM 5.00 - Material Balance - multitank starting point.mbi
File Tool Options PVT Input History Matching Production Prediction View Units Help
Add Tank
Add Trans.
Add Well
Connect
Move
Tank-1
Tank-2

These reservoirs will now be connected by selecting the “Connect” button on the side panel of **MBAL**:


MBAL 8.00 - IPM 5.00 - Material Balance - multitank starting point.mbi
File Tool Options PVT Input History Matching Production Prediction View Units Help
Add Tank
Add Trans.
Add Well
Connect
Move
Tank-1
Tank-2

Using the mouse, drag and drop from one reservoir to the other. This will now create a link between the reservoirs and the transmissibility screen will automatically be prompted:


Transmissibility Input Data - Transmissibility Parameters
Done
Cancel
Help
Setup
Production History
Prior
Next >>
Validate

Transmissibility: Trans01 ☐ Disabled

Tank Connection
Between: Tank-1 and Tank-2
Allow Flow: Both Directions

Transmissibility
C: RB/day*cp/psi

Breakthrough Constraints
Water Saturation: * fraction
Gas Saturation: * fraction
Oil Saturation: * fraction
☐ Shift Relative Permeability to Breakthrough

Permeability Correction of Transmissibility
N: *

Relative Permeabilities
Rel Perms: Use Tank

Pressure Threshold
● No Threshold
○ Use Threshold with Equal Potentials
○ Use Threshold with Unequal Potentials
Pressure Threshold: 1000 psi

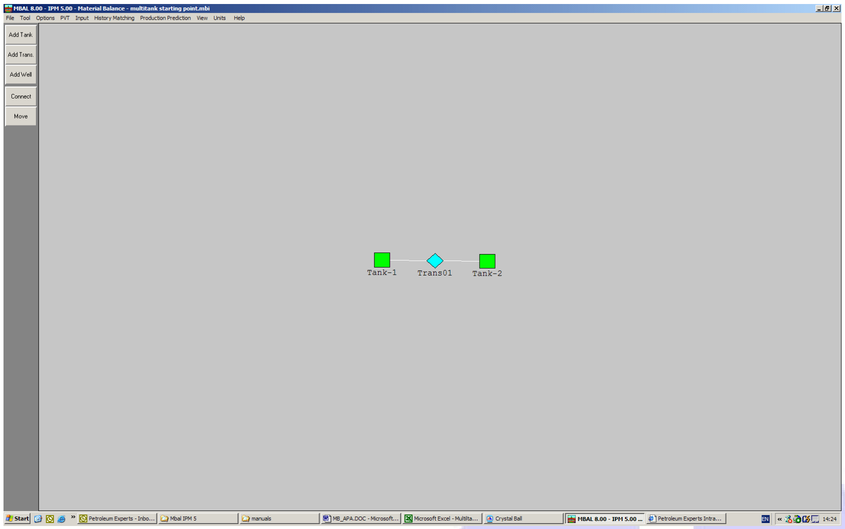
Production History
☐ Use Production History

Select this option if you have entered production history and you wish to use it to calculate transmissibility rates for the history simulation and the history part of the prediction.

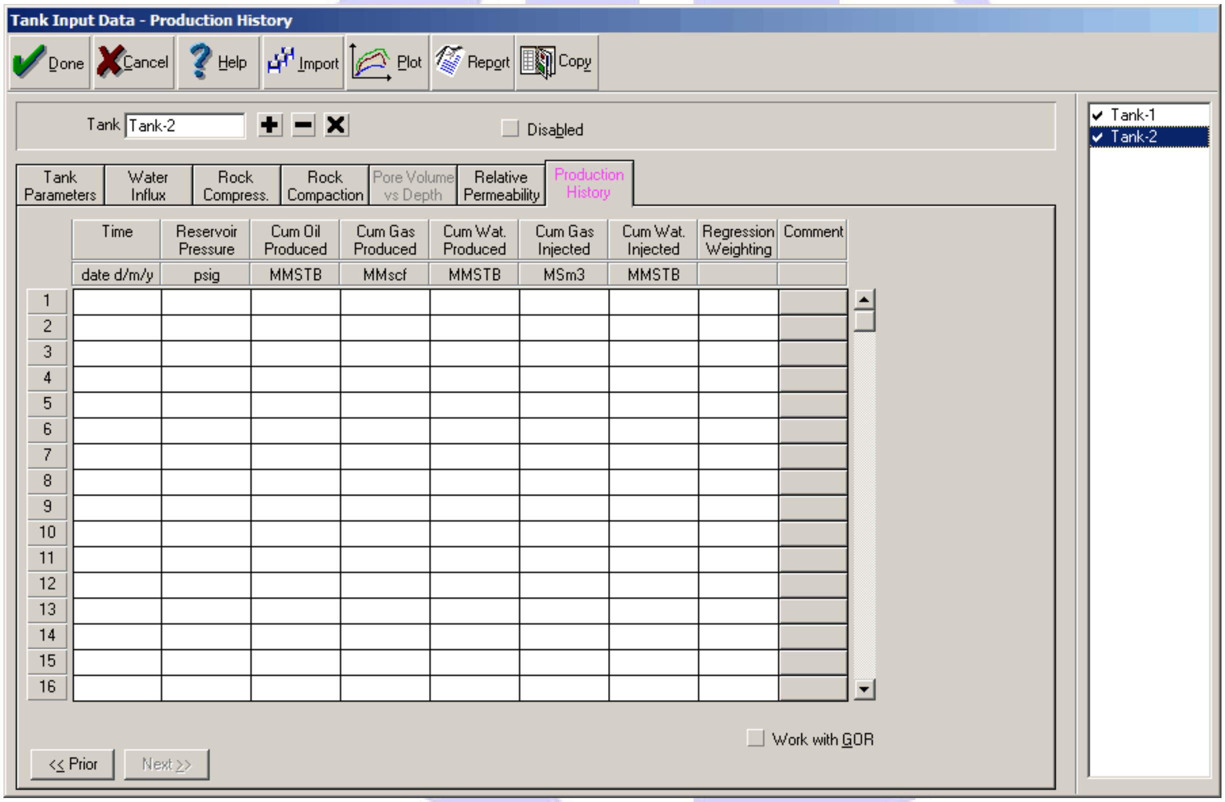
✓ Trans01

A transmissibility 'C' of 5 can be entered as a first guess.

Going back to the main screen, the two reservoirs will now appear connected.


MBAL 8.00 - IPM 5.00 - Material Balance - multitank starting point.mbi
File Tool Options PVT Input History Matching Production Prediction View Units Help
Add Tank
Add Trans
Add Well
Connect
Move
Tank-1
Trans01
Tank-2

Note: Since the second reservoir has been created as a copy of the first one, it also includes the production history. This needs to be removed as only the first reservoir was producing. Right click anywhere in the history page of the second reservoir and select "Clear Table". This will delete all the historical production.

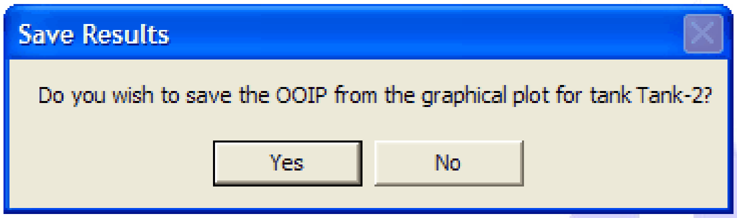

Tank Input Data - Production History
Done
Cancel
Help
Import
Plot
Report
Copy
Disabled
Tank-1
Tank-2
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
Time
Reservoir Pressure
Cum Oil Produced
Cum Gas Produced
Cum Wat. Produced
Cum Gas Injected
Cum Wat. Injected
Regression Weighting
Comment
date d/m/y
psig
MMSTB
MMscf
MMSTB
MSm3
MMSTB
Work with GOR
<< Prior
Next >>

Tank Tank-2

☐ Disabled

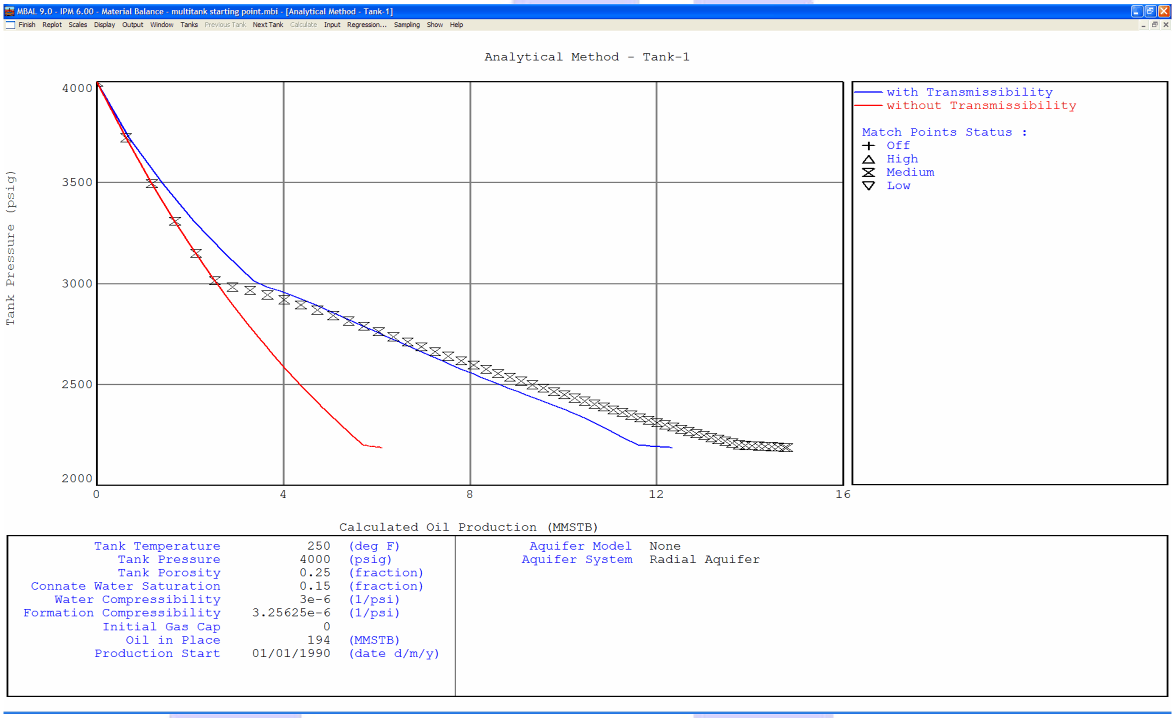
☐ Work with GOR

Go back to the Main screen of MBAL and click on **History Matching|All**, the plots for Tank 2 will be seen. Select **Tanks|Tanks 1** to display the plots for Tank 1. A message will be flashed as shown below. Click on 'NO'.


Save Results
Yes
No

Do you wish to save the OOIP from the graphical plot for tank Tank-2?

It can now be seen that the second reservoir has had an impact on the overall performance of the model.

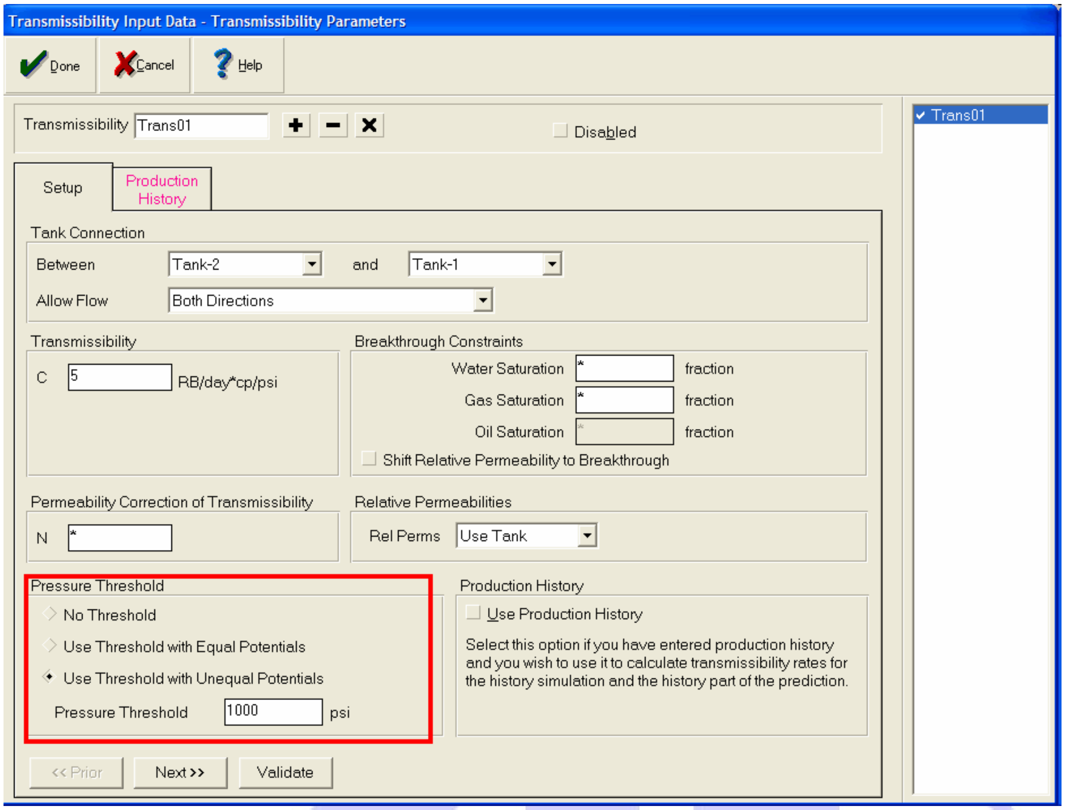

MBAL 9.0 - IPM 6.00 - Material Balance - multitank starting point.mbi - [Analytical Method - Tank-1]
Finish Replot Scales Display Output Window Tanks Previous Tank Next Tank Calculate Input Regression... Sampling Show Help
Analytical Method - Tank-1
Tank Pressure (psig)
4000
3500
3000
2500
2000
0
4
8
12
16
Calculated Oil Production (MMSTB)
with Transmissibility
without Transmissibility
Match Points Status :
+ Off
△ High
⧖ Medium
▽ Low

```
         Tank Temperature         250   (deg F)        Aquifer Model   None
            Tank Pressure        4000   (psig)        Aquifer System   Radial Aquifer
            Tank Porosity        0.25   (fraction)
Connate Water Saturation         0.15   (fraction)
   Water Compressibility         3e-6   (1/psi)
Formation Compressibility  3.25625e-6   (1/psi)
         Initial Gas Cap            0
            Oil in Place          194   (MMSTB)
        Production Start   01/01/1990   (date d/m/y)
```

Since we know that the barrier between the two reservoirs had been closed for some time before it was broken, this needs to be reproduced by the model. In other words, the second reservoir should only be allowed to provide support after the pressure in the first reservoir has dropped to the point shown in the figure above.

MBAL allows the transmissibility to become active after a certain pressure drop has been reached between the reservoirs. This is done using the 'Pressure Threshold' options.

Activate the pressure threshold option and enter a value of 1000 psi for the threshold.



Transmissibility Input Data - Transmissibility Parameters

Transmissibility: Trans01

☐ Disabled

Tank Connection

Between: Tank-2 and Tank-1

Allow Flow: Both Directions

Transmissibility

C: 5 RB/day*cp/psi

Breakthrough Constraints

Water Saturation: * fraction

Gas Saturation: * fraction

Oil Saturation: * fraction

☐ Shift Relative Permeability to Breakthrough

Permeability Correction of Transmissibility

N: *

Relative Permeabilities

Rel Perms: Use Tank

Pressure Threshold

○ No Threshold

○ Use Threshold with Equal Potentials

● Use Threshold with Unequal Potentials

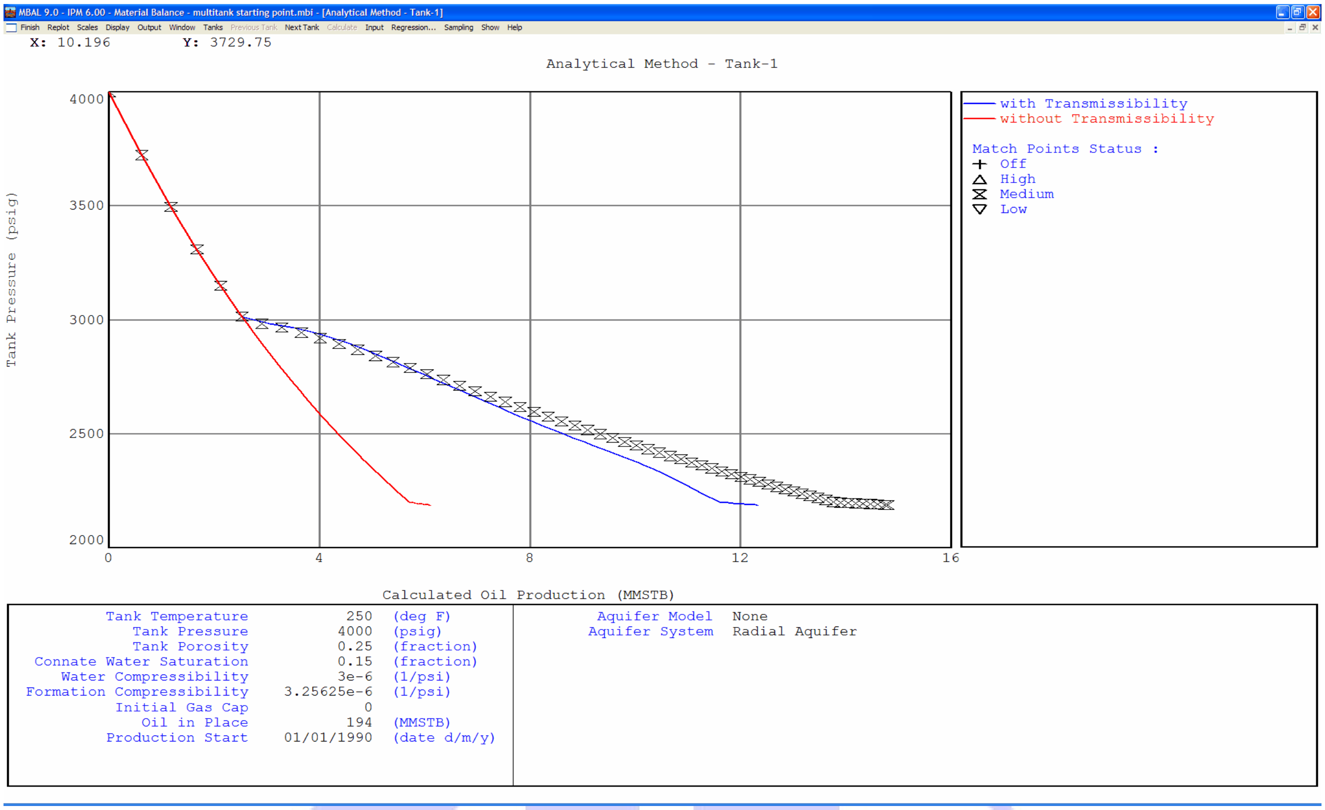
Pressure Threshold: 1000 psi

Production History

☐ Use Production History

Select this option if you have entered production history and you wish to use it to calculate transmissibility rates for the history simulation and the history part of the prediction.

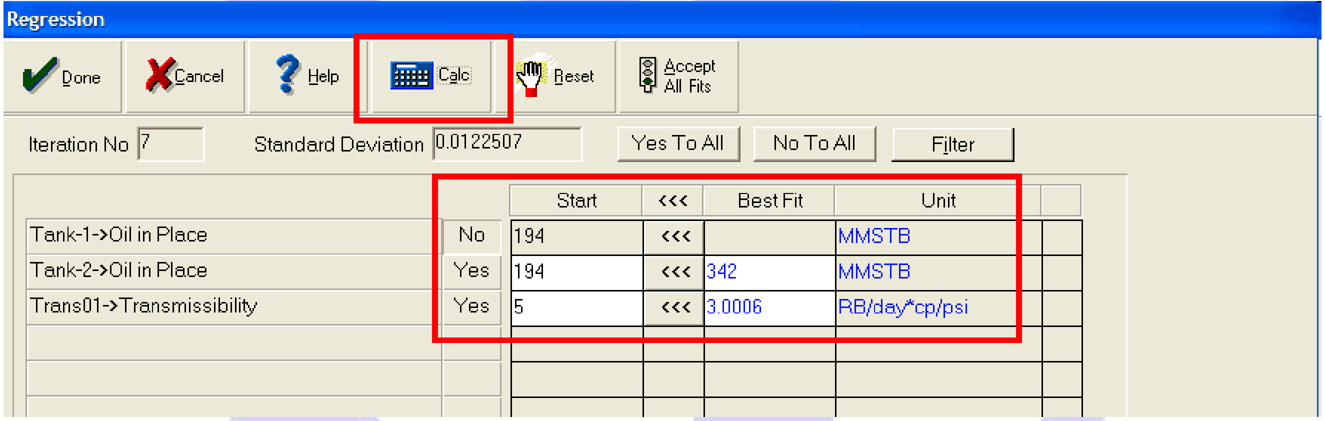
The analytical method will show the effect of the second reservoir only when the dP between them reaches 1000 psi:


MBAL 9.0 - IPM 6.00 - Material Balance - multitank starting point.mbi - [Analytical Method - Tank-1]
Finish Replot Scales Display Output Window Tanks Previous Tank Next Tank Calculate Input Regression... Sampling Show Help
X: 10.196 Y: 3729.75
Analytical Method - Tank-1
Tank Pressure (psig)
4000
3500
3000
2500
2000
0
4
8
12
16
Calculated Oil Production (MMSTB)
with Transmissibility
without Transmissibility
Match Points Status :
+ Off
△ High
⧖ Medium
▽ Low

Tank Temperature	250	(deg F)
Tank Pressure	4000	(psig)
Tank Porosity	0.25	(fraction)
Connate Water Saturation	0.15	(fraction)
Water Compressibility	3e-6	(1/psi)
Formation Compressibility	3.25625e-6	(1/psi)
Initial Gas Cap	0	
Oil in Place	194	(MMSTB)
Production Start	01/01/1990	(date d/m/y)

Aquifer Model None
Aquifer System Radial Aquifer

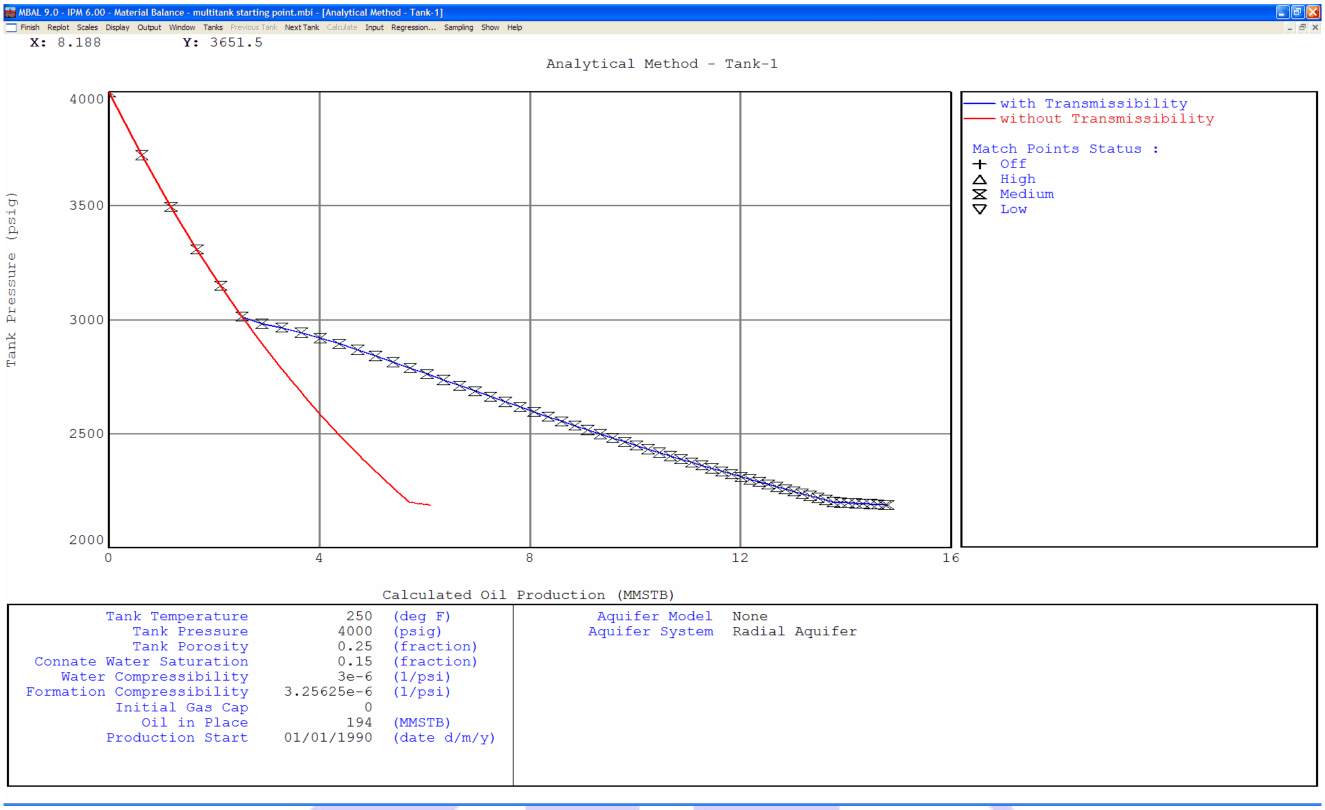
Regression can now be carried out as usual, considering only the new parameters Accept the results by clicking on 'Accept All Fits.'


Regression
Done
Cancel
Help
Calc
Reset
Accept All Fits
Yes To All
No To All
Filter

Iteration No 7
Standard Deviation 0.0122507

		Start	<<<	Best Fit	Unit
Tank-1->Oil in Place	No	194	<<<		MMSTB
Tank-2->Oil in Place	Yes	194	<<<	342	MMSTB
Trans01->Transmissibility	Yes	5	<<<	3.0006	RB/day*cp/psi

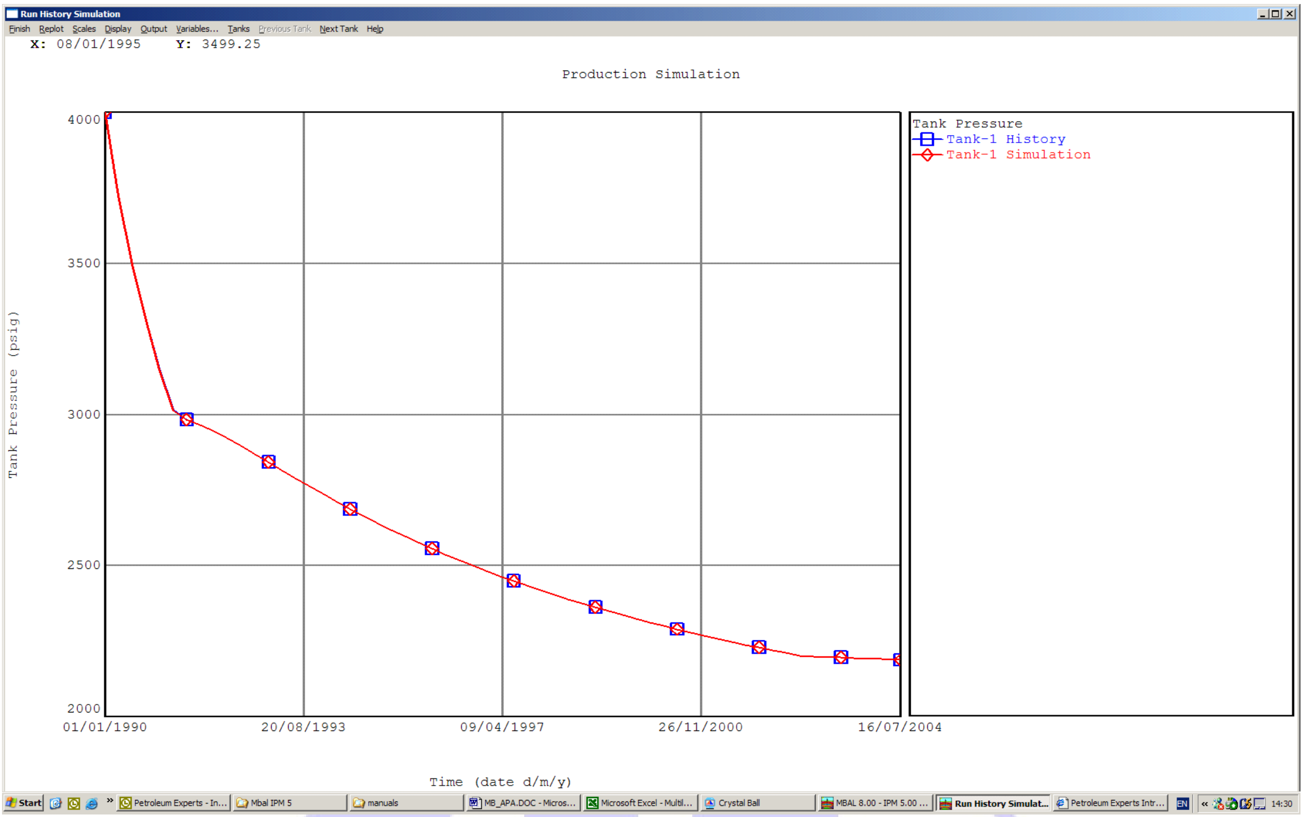
And the result is a good match between history and Model:


MBAL 9.0 - IPM 6.00 - Material Balance - multitank starting point.mbi - [Analytical Method - Tank-1]
Finish Replot Scales Display Output Window Tanks Previous Tank Next Tank Calculate Input Regression... Sampling Show Help
X: 8.188
Y: 3651.5
Analytical Method - Tank-1
Tank Pressure (psig)
4000
3500
3000
2500
2000
0
4
8
12
16
Calculated Oil Production (MMSTB)
with Transmissibility
without Transmissibility
Match Points Status :
+ Off
△ High
⧖ Medium
▽ Low

Tank Temperature	250	(deg F)
Tank Pressure	4000	(psig)
Tank Porosity	0.25	(fraction)
Connate Water Saturation	0.15	(fraction)
Water Compressibility	3e-6	(1/psi)
Formation Compressibility	3.25625e-6	(1/psi)
Initial Gas Cap	0	
Oil in Place	194	(MMSTB)
Production Start	01/01/1990	(date d/m/y)

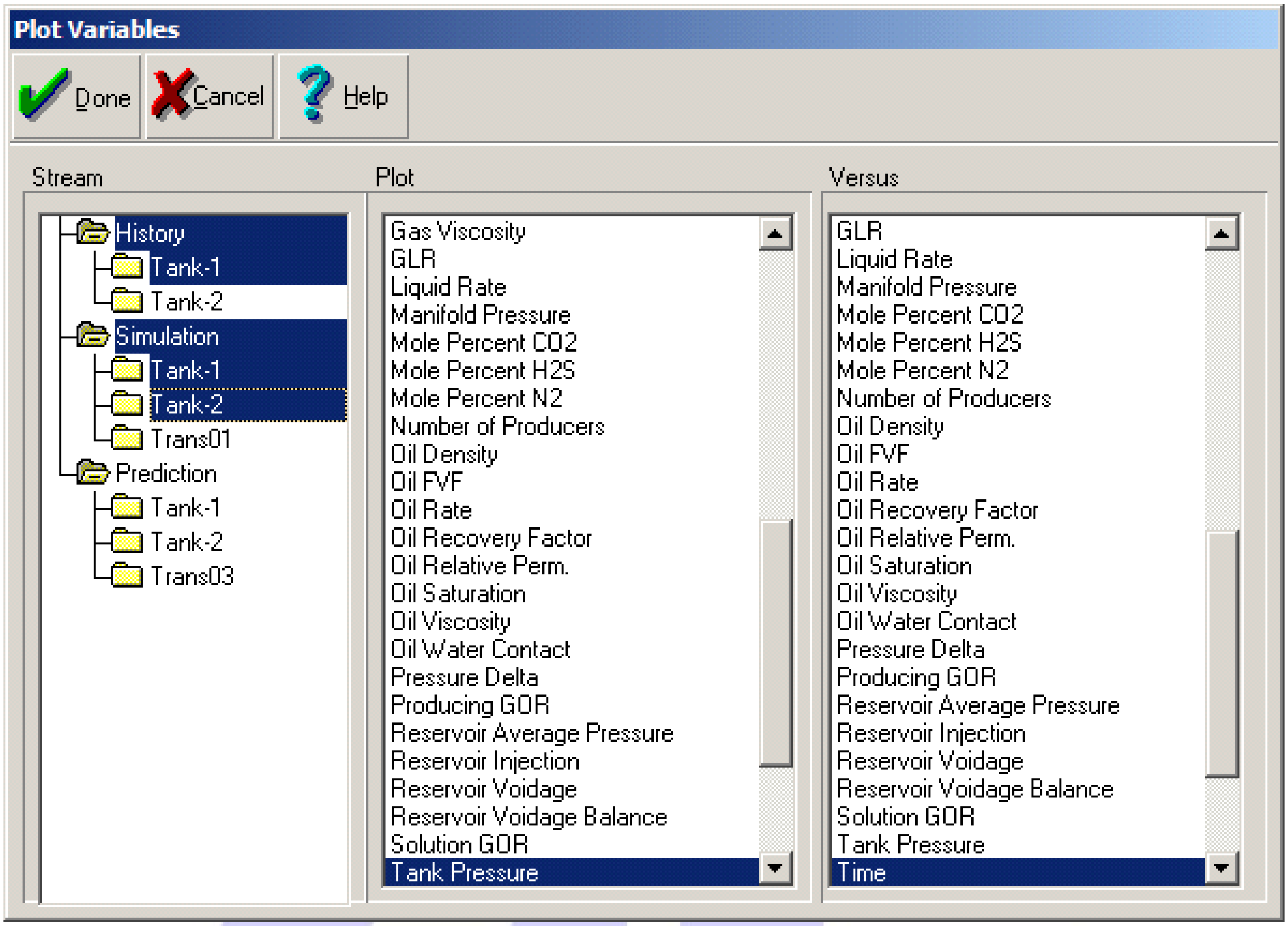
Aquifer Model None
Aquifer System Radial Aquifer

The same result can be confirmed from the simulation calculations:


Run History Simulation
Finish Replot Scales Display Output Variables... Tanks Previous Tank Next Tank Help
X: 08/01/1995 Y: 3499.25
Production Simulation
Tank Pressure (psig)
4000
3500
3000
2500
2000
01/01/1990
20/08/1993
09/04/1997
26/11/2000
16/07/2004
Time (date d/m/y)
Tank Pressure
Tank-1 History
Tank-1 Simulation

In order to investigate how both tanks have been depleted, the “Variables” button can be selected and in the following screen select to view the Tank pressure of both reservoirs:

PE watermark

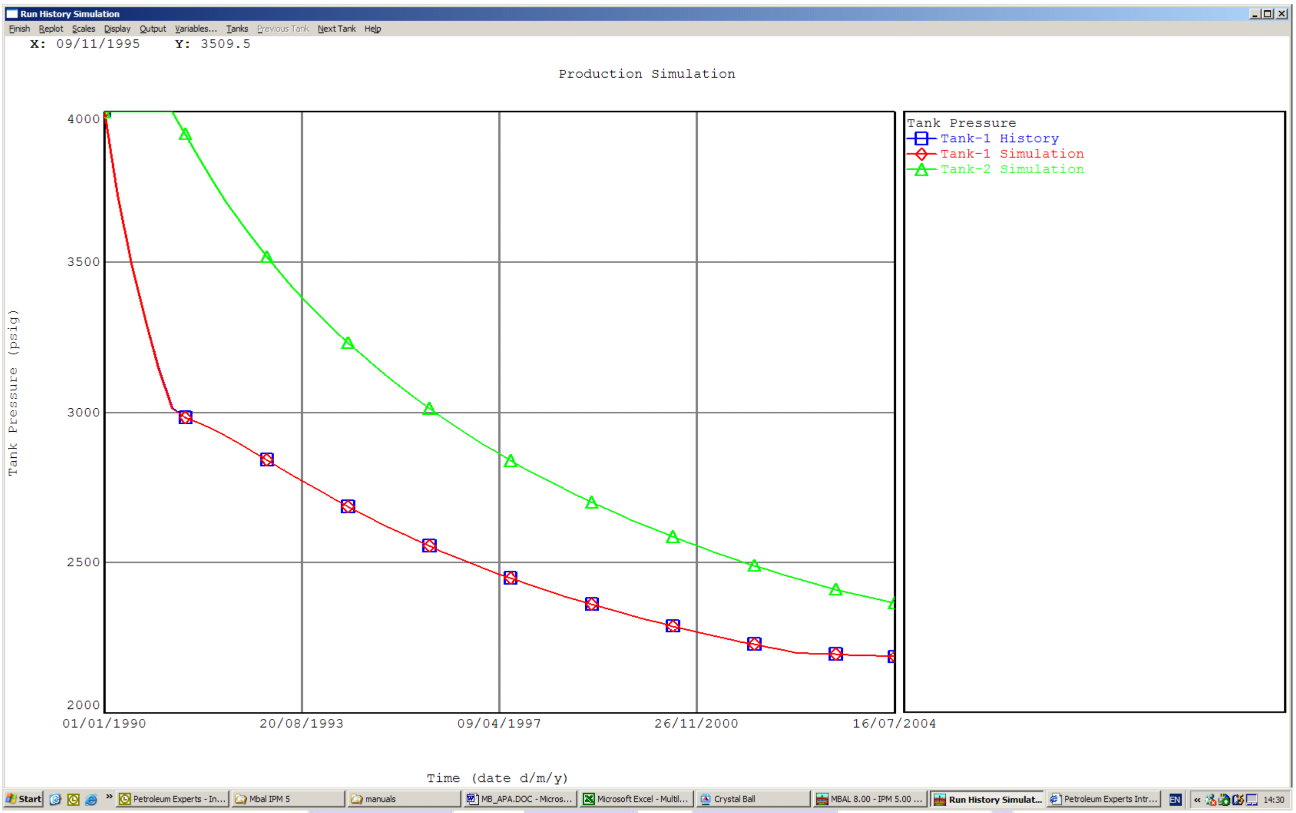


Stream
- History
  - Tank-1
  - Tank-2
- Simulation
  - Tank-1
  - Tank-2
  - Trans01
- Prediction
  - Tank-1
  - Tank-2
  - Trans03

Plot
Gas Viscosity
GLR
Liquid Rate
Manifold Pressure
Mole Percent CO2
Mole Percent H2S
Mole Percent N2
Number of Producers
Oil Density
Oil FVF
Oil Rate
Oil Recovery Factor
Oil Relative Perm.
Oil Saturation
Oil Viscosity
Oil Water Contact
Pressure Delta
Producing GOR
Reservoir Average Pressure
Reservoir Injection
Reservoir Voidage
Reservoir Voidage Balance
Solution GOR
Tank Pressure

Versus
GLR
Liquid Rate
Manifold Pressure
Mole Percent CO2
Mole Percent H2S
Mole Percent N2
Number of Producers
Oil Density
Oil FVF
Oil Rate
Oil Recovery Factor
Oil Relative Perm.
Oil Saturation
Oil Viscosity
Oil Water Contact
Pressure Delta
Producing GOR
Reservoir Average Pressure
Reservoir Injection
Reservoir Voidage
Reservoir Voidage Balance
Solution GOR
Tank Pressure
Time

It can be seen from the following plot that the second reservoir does not start depleting until the dP between the two reservoirs reaches 1000psi.


Run History Simulation
Finish Replot Scales Display Output Variables... Tanks Previous Tank Next Tank Help
X: 09/11/1995 Y: 3509.5
Production Simulation
Tank Pressure (psig)
4000
3500
3000
2500
2000
01/01/1990
20/08/1993
09/04/1997
26/11/2000
16/07/2004
Time (date d/m/y)
Tank Pressure
Tank-1 History
Tank-1 Simulation
Tank-2 Simulation
Start
Petroleum Experts - In...
Mbal IPM 5
manuals
MB_APA.DOC - Micros...
Microsoft Excel - Multi...
Crystal Ball
MBAL 8.00 - IPM 5.00 ...
Run History Simulat...
Petroleum Experts Intr...
EN
14:30

3.3 Coalbed Methane Material Balance

Objectives

This example is designed to illustrate:

- how to set-up a material balance model for a coalbed methane field
- how to estimate Original Adsorbed Gas in Place
- how to run a prediction forecast using well models (inflow & outflow)

Statement of the problem

The coalbed methane field "CBM01" has been discovered and will start producing from 01/01/2009.

Fluid properties and reservoir properties are available.

It is requested to:

- construct a material balance model
- Use the calculate option that uses the entered Langmuir Isotherm data to estimate the OGIP (free and adsorbed gas) based on the rock volume.

- Determine the required de-watering period for gas to desorb, and perform a production prediction to understand gas well performance and field recovery.
- The prediction period is from 01/01/2009 until 01/01/2014
- The gas producing well will be produced at a fixed well head flowing pressure of 35 psig.
- The ESP de-watering well will be produced at a fixed well head flowing pressure of 150 psig.

Workflow

The recommended workflow is very similar to the one applied for material balance in conventional reservoirs:

- Enter the PVT data
- Enter the basic reservoir data including the description of the Langmuir isotherm
- Specify boundary conditions for the prediction runs: start and end date, manifold pressure and any other meaningful constraints
- Create and describe prediction wells with VLP and IPR
- Schedule wells, define reporting frequency and perform the prediction run.

Input data

The following input data will be required:

- Fluid properties
- Basic reservoir data including the description of the adsorption / desorption process (Langmuir Isotherm)
- Well models (Inflow, lift curves) for the prediction wells.

PVT Data

Gas Gravity	0.6 (Air = 1)
Separator pressure	0 psig
Condensate to Gas Ratio	0 stb/MMscf
Water salinity	25000 ppm
Mole percent of H2S	0%
Mole Percent of CO2	0%
Mole percent of N2	0%

Basic Reservoir data

Tank type	Gas
Reservoir temperature	80 degF
Initial Pressure	500 psig
Coal porosity	1%
Connate water saturation	100%
Water compressibility	Use correlations
Estimated Original Gas In Place (free + adsorbed)	24000 MMscf
Start of production	01/01/2009
Aquifer	None
Rock compressibility	7.5E-6 (1/psi)

Langmuir Isotherm

Adsorbed Gas entry Method	Surface / Volume of rock: volume of gas collected on to the surface of the rock per volume or rock at standard conditions
Coal type	Undersaturated
Test type	as received
Langmuir volume constant	30 scf/ft^3
Langmuir pressure	500 psig
Maximum adsorbed volume	25 scf/ft^3

Relative permeabilities in Corey form

Phase	***Residual saturation***	***Endpoint***	***Exponent***
Water	0.25	0.01	3
Gas	0.05	0.8	3

Production Prediction: Boundary Conditions

Prediction type	Production Profile Using Well Models
Prediction start	01/01/2009
Prediction end	01/01/2014
Gas Production Manifold Pressure	35 psig
Water Production Manifold Pressure	150 psig

Production Prediction: Gas Well Model

Well type:	Dry Gas Producer
Inflow Performance type:	C and n
C-value:	0.0045 Mscf/d/psi^2
n-value (Non-Darcy exponent):	0.95
Gas Production Manifold Pressure:	35 psig
Well lift tables in PETEX format:	?:\Program Files\Petroleum Experts\IPM 7.5\Samples\MBAL\Material Balance for CBM\CBM_GAS_PRODUCER.TPD

Production Prediction: ESP Well Model

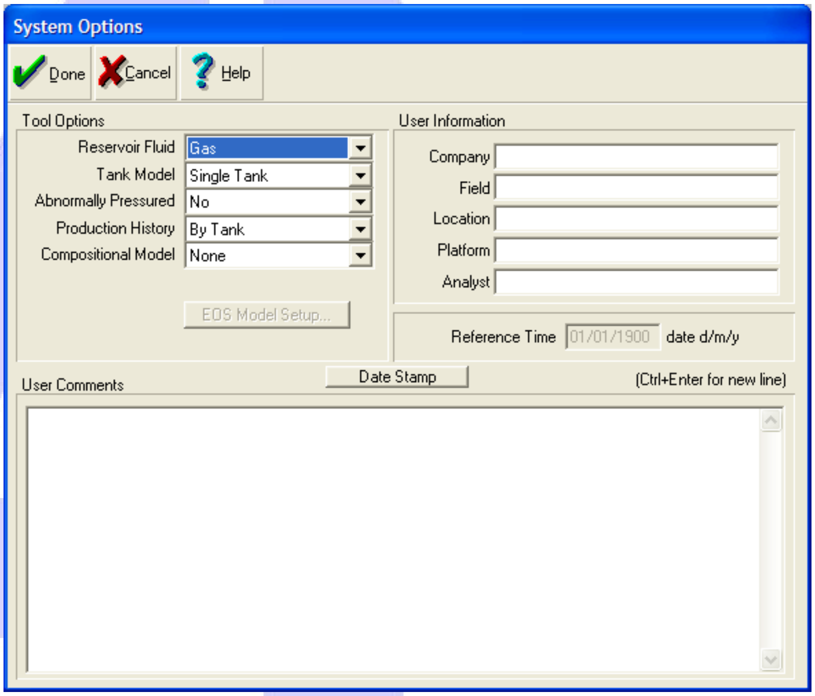
Well type	CBM Water Producer (ESP)
Inflow Performance type	PI
PI value	1 stb/d/psi
Water Well Manifold Pressure	150 psig
ESP Operating Frequency	70 Hertz
Well lift tables in PETEX format	?:\Program Files\Petroleum Experts\IPM 7.5\Samples\MBAL\Material Balance for CBM\CBM_WATER_PRODUCER.TPD

3.3.1 Starting the Model

Clearing any previous calculations by selecting **FILE|NEW**; the detail concerning the type of model to be defined can be entered.

Select **TOOL|MATERIAL BALANCE**, and then click **OPTIONS** from the main menu.

The following selections can be made:



System Options

Tool Options

Reservoir Fluid: Gas
Tank Model: Single Tank
Abnormally Pressured: No
Production History: By Tank
Compositional Model: None

User Information

Company:
Field:
Location:
Platform:
Analyst:

Reference Time: 01/01/1900 date d/m/y

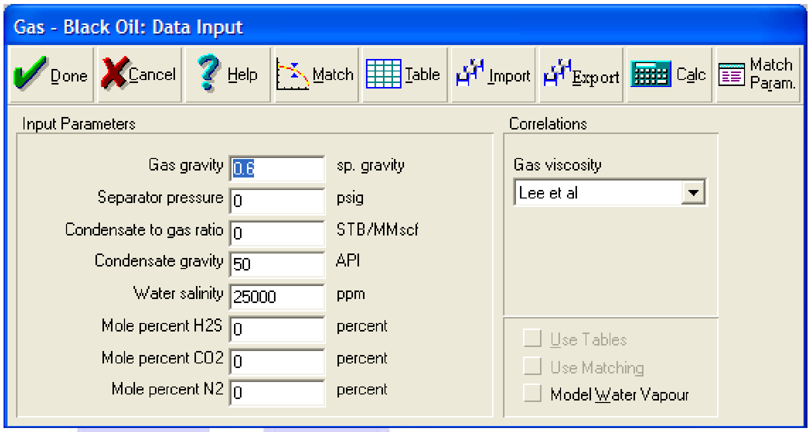
User Comments

(Ctrl+Enter for new line)

Click **DONE** to return to the main menu.

3.3.2 PVT Menu

Select **PVT|FLUID PROPERTIES** and enter the following PVT data:


Gas - Black Oil: Data Input
Done
Cancel
Help
Match
Table
Import
Export
Calc
Match Param.

Input Parameters

Gas gravity	0.6	sp. gravity
Separator pressure	0	psig
Condensate to gas ratio	0	STB/MMscf
Condensate gravity	50	API
Water salinity	25000	ppm
Mole percent H2S	0	percent
Mole percent CO2	0	percent
Mole percent N2	0	percent

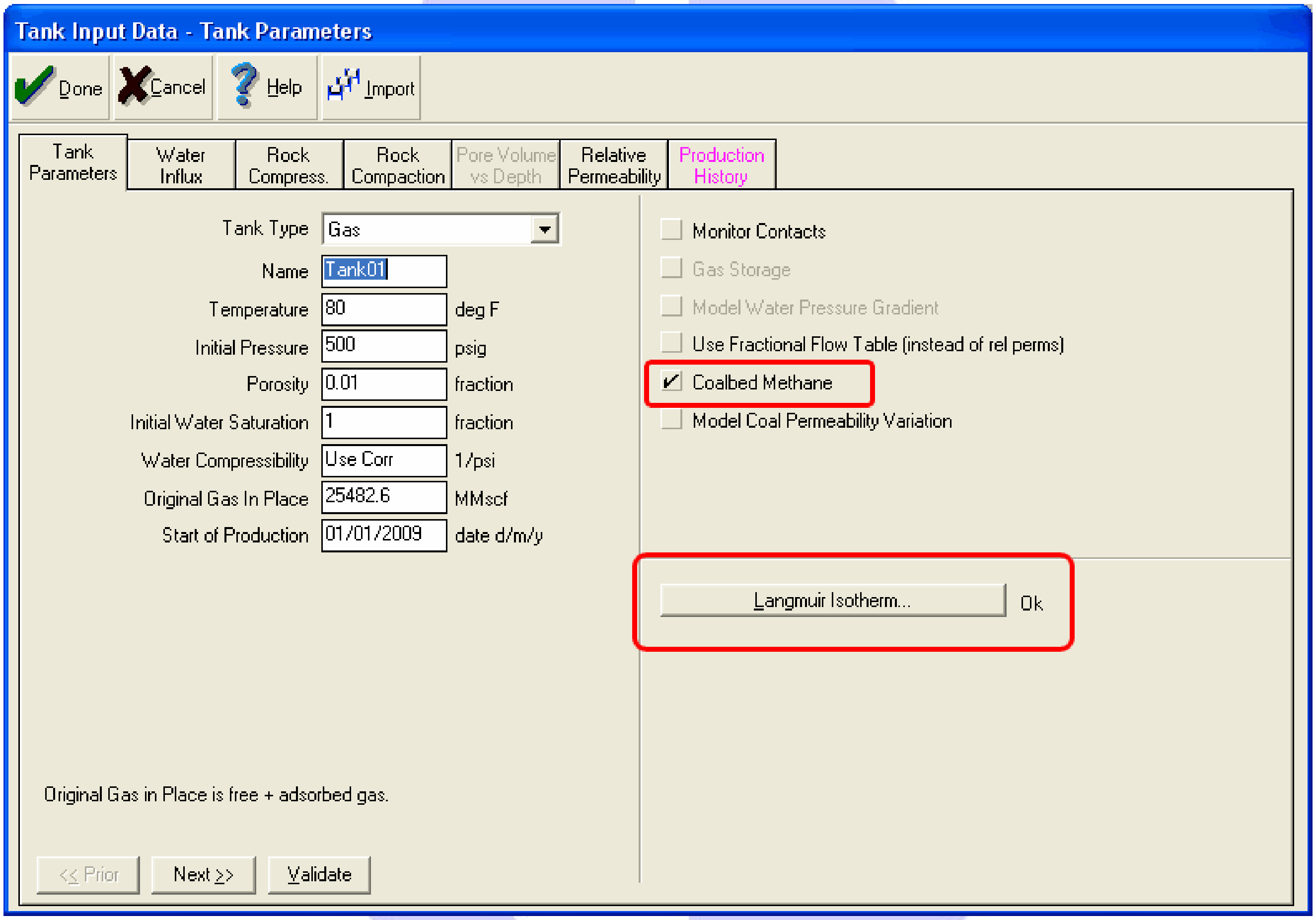
Correlations

Gas viscosity: Lee et al

☐ Use Tables
☐ Use Matching
☐ Model Water Vapour

3.3.3 Reservoir Input

Enter the following tank data and select the Coalbed Methane option:


Tank Input Data - Tank Parameters
Done
Cancel
Help
Import
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
Langmuir Isotherm...
<< Prior
Next >>
Validate

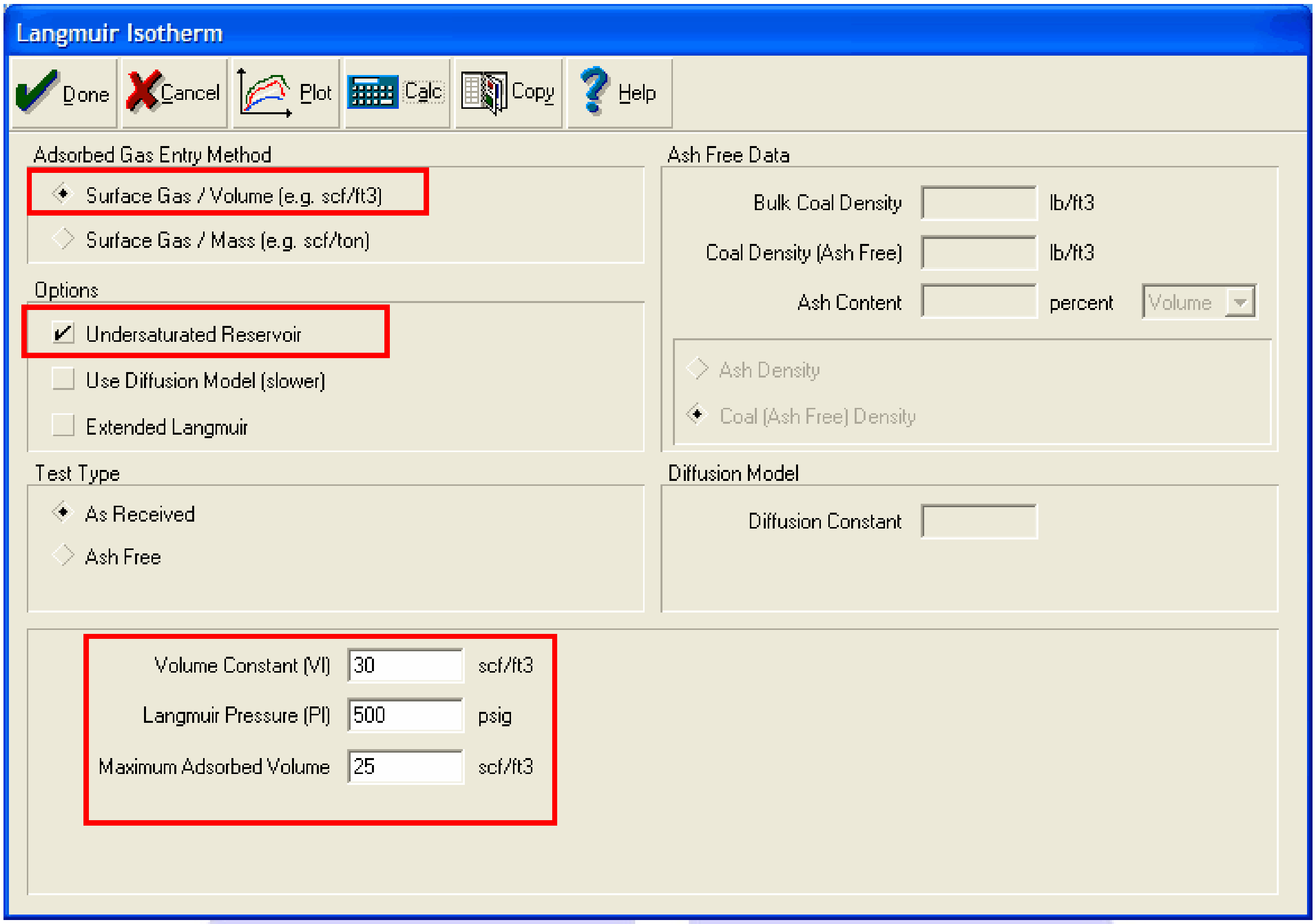
Tank Type	Gas	
Name	Tank01	
Temperature	80	deg F
Initial Pressure	500	psig
Porosity	0.01	fraction
Initial Water Saturation	1	fraction
Water Compressibility	Use Corr	1/psi
Original Gas In Place	25482.6	MMscf
Start of Production	01/01/2009	date d/m/y

☐ Monitor Contacts
☐ Gas Storage
☐ Model Water Pressure Gradient
☐ Use Fractional Flow Table (instead of rel perms)
☑ Coalbed Methane
☐ Model Coal Permeability Variation

Ok

Original Gas in Place is free + adsorbed gas.

Once the above tank data has been entered, select the Langmuir Isotherm button shown in the above screen shot and enter the following data:


Langmuir Isotherm
Done
Cancel
Plot
Calc
Copy
Help
Ash Free Data
Ash Density
Coal (Ash Free) Density
Volume
Diffusion Model

Adsorbed Gas Entry Method

- ● Surface Gas / Volume (e.g. scf/ft3)
- ○ Surface Gas / Mass (e.g. scf/ton)

Options

- ☑ Undersaturated Reservoir
- ☐ Use Diffusion Model (slower)
- ☐ Extended Langmuir

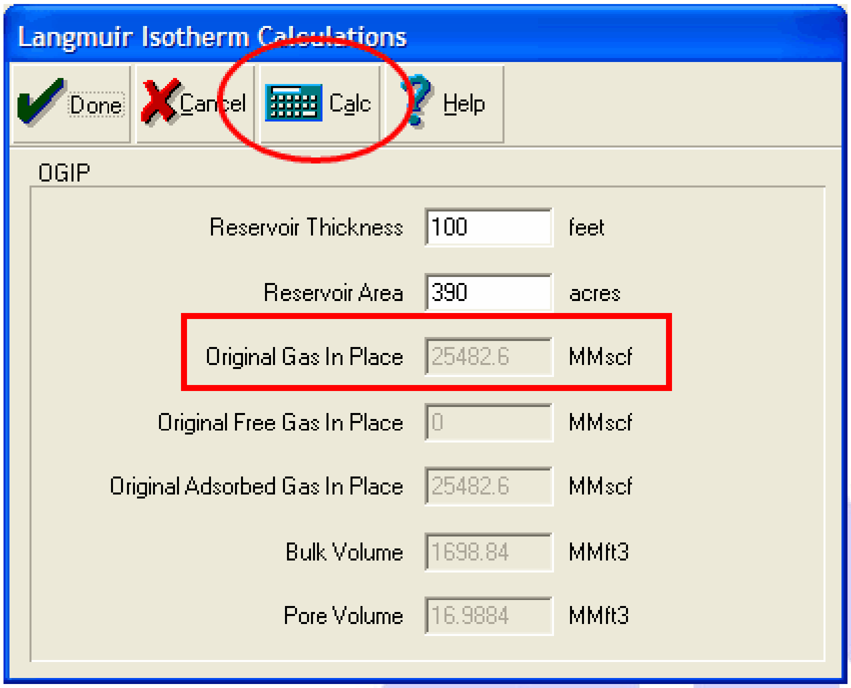
Test Type

- ● As Received
- ○ Ash Free

Bulk Coal Density lb/ft3
Coal Density (Ash Free) lb/ft3
Ash Content percent
Diffusion Constant

Volume Constant (Vl) 30 scf/ft3
Langmuir Pressure (Pl) 500 psig
Maximum Adsorbed Volume 25 scf/ft3

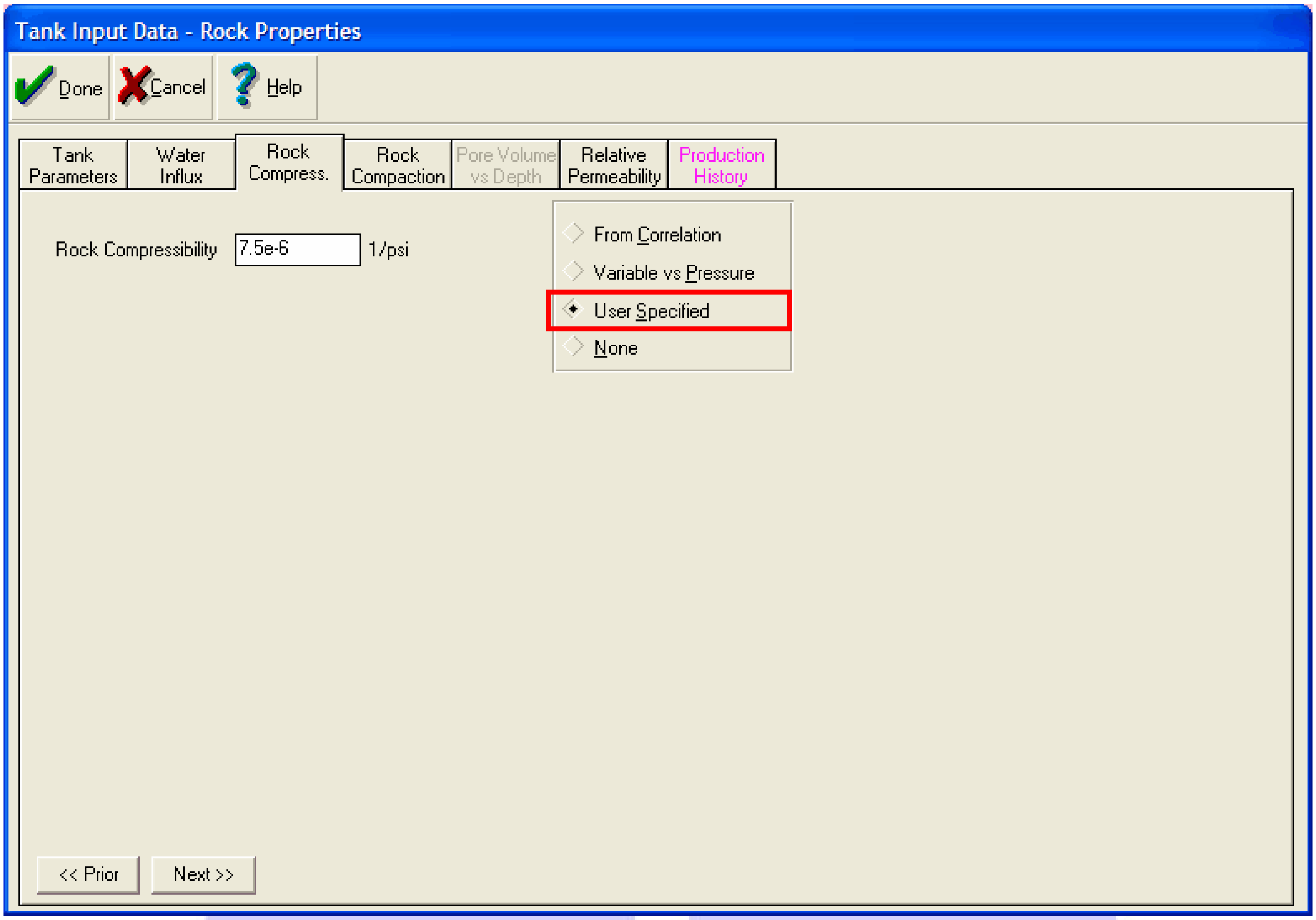
The **Calc** feature in the above screen is very useful in estimating the OGIP (free + adsorbed gas). If knowledge of the reservoir thickness and area are known, then **MBAL** can estimate the volume of the free gas and the adsorbed gas in place, the bulk volume and the pore volume of the system:


Langmuir Isotherm Calculations
Done
Cancel
Calc
Help
OGIP

Reservoir Thickness 100 feet
Reservoir Area 390 acres
Original Gas In Place 25482.6 MMscf
Original Free Gas In Place 0 MMscf
Original Adsorbed Gas In Place 25482.6 MMscf
Bulk Volume 1698.84 MMft3
Pore Volume 16.9884 MMft3

Once the above calculation has been completed, the calculated OGIP value will be automatically updated in the Tank Parameters section.

3.3.4 Rock Properties

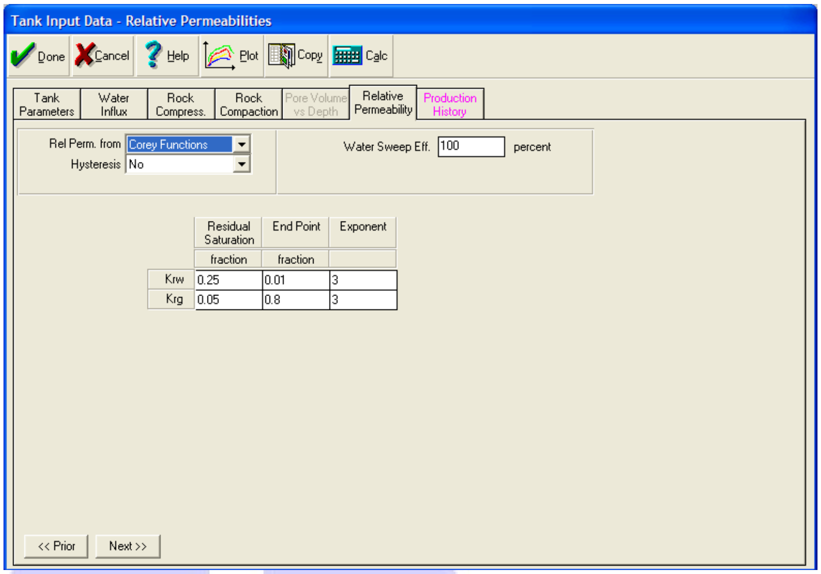

Tank Input Data - Rock Properties
Done
Cancel
Help
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
From Correlation
Variable vs Pressure
None
<< Prior
Next >>

Rock Compressibility 7.5e-6 1/psi

● User Specified

3.3.5 Relative Permeability

The next step is to select the **Relative Permeability** tab where the following relative permeability data can be entered:

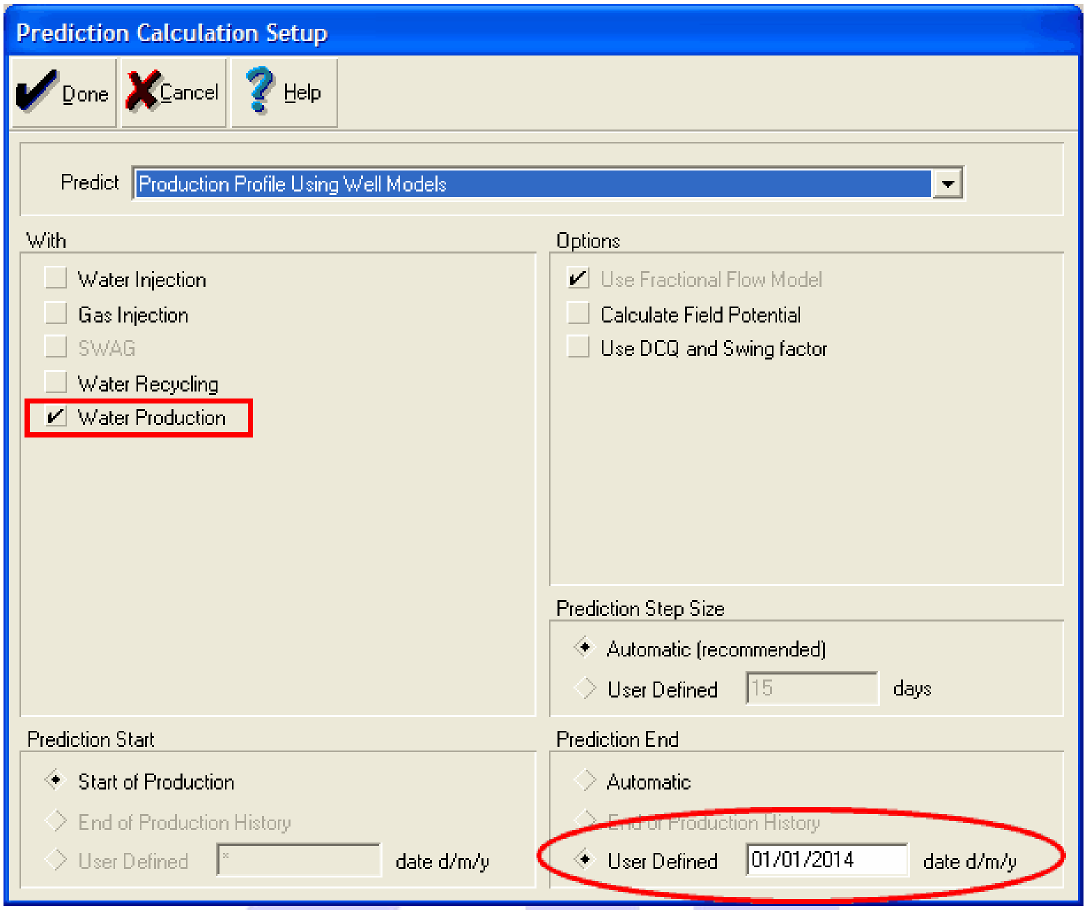

Tank Input Data - Relative Permeabilities
Done
Cancel
Help
Plot
Copy
Calc
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
<< Prior
Next >>

Rel Perm. from Corey Functions
Hysteresis No
Water Sweep Eff. 100 percent

	Residual Saturation	End Point	Exponent
	fraction	fraction	
Krw	0.25	0.01	3
Krg	0.05	0.8	3

3.3.6 Prediction

Select Production Prediction | Prediction Setup and enter the following prediction start and end dates:



Prediction Calculation Setup
Done
Cancel
Help

Predict: Production Profile Using Well Models

With
- ☐ Water Injection
- ☐ Gas Injection
- ☐ SWAG
- ☐ Water Recycling
- ☑ Water Production

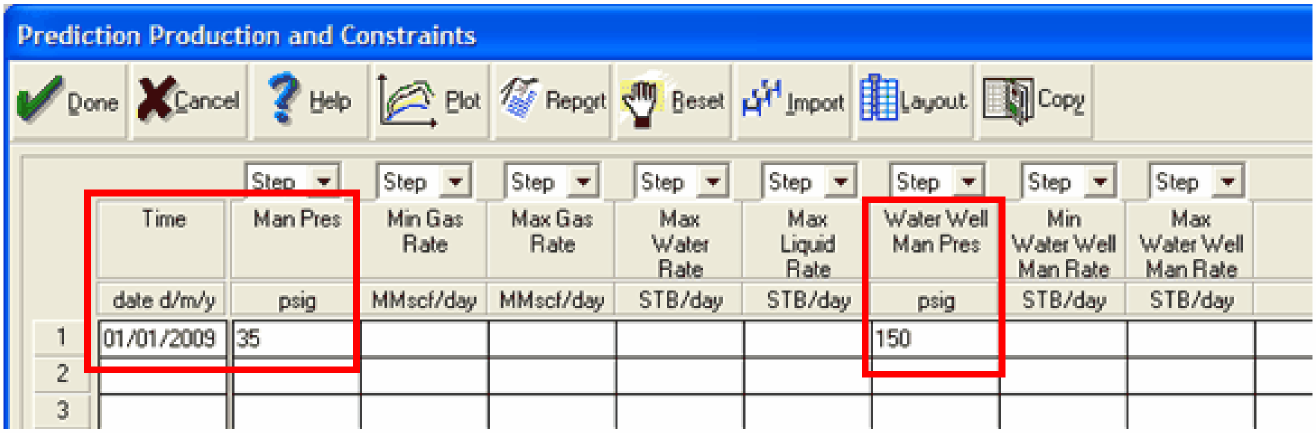
Options
- ☑ Use Fractional Flow Model
- ☐ Calculate Field Potential
- ☐ Use DCQ and Swing factor

Prediction Step Size
- ● Automatic (recommended)
- ○ User Defined 15 days

Prediction Start
- ● Start of Production
- ○ End of Production History
- ○ User Defined date d/m/y

Prediction End
- ○ Automatic
- ○ End of Production History
- ● User Defined 01/01/2014 date d/m/y

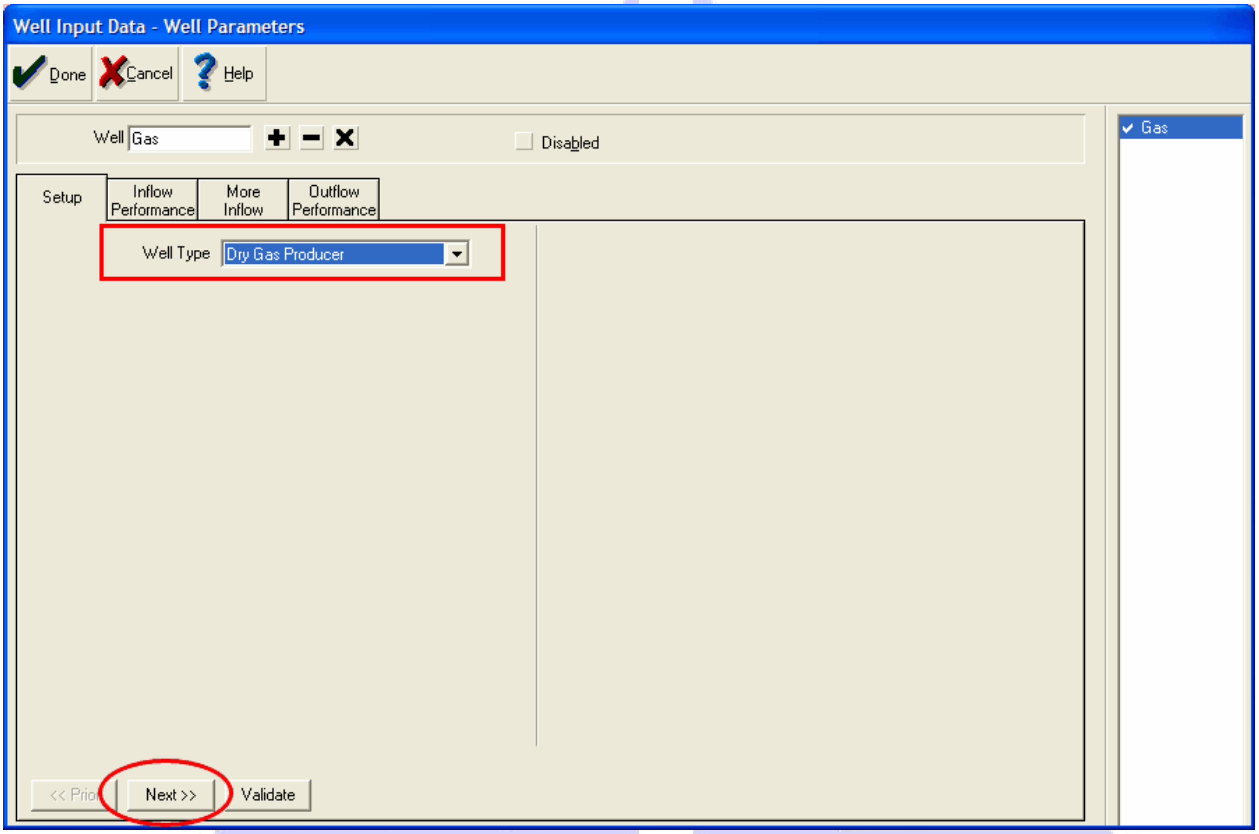
In the next section (Production Prediction | Production and Constraints), the prediction start date and manifold pressures for the gas and water wells need to be specified, no other constraints will be used for this example:



Prediction Production and Constraints
Done
Cancel
Help
Plot
Report
Reset
Import
Layout
Copy

	Time	Man Pres	Min Gas Rate	Max Gas Rate	Max Water Rate	Max Liquid Rate	Water Well Man Pres	Min Water Well Man Rate	Max Water Well Man Rate
		Step	Step	Step	Step	Step	Step	Step	Step
	date d/m/y	psig	MMscf/day	MMscf/day	STB/day	STB/day	psig	STB/day	STB/day
1	01/01/2009	35					150		
2									
3									

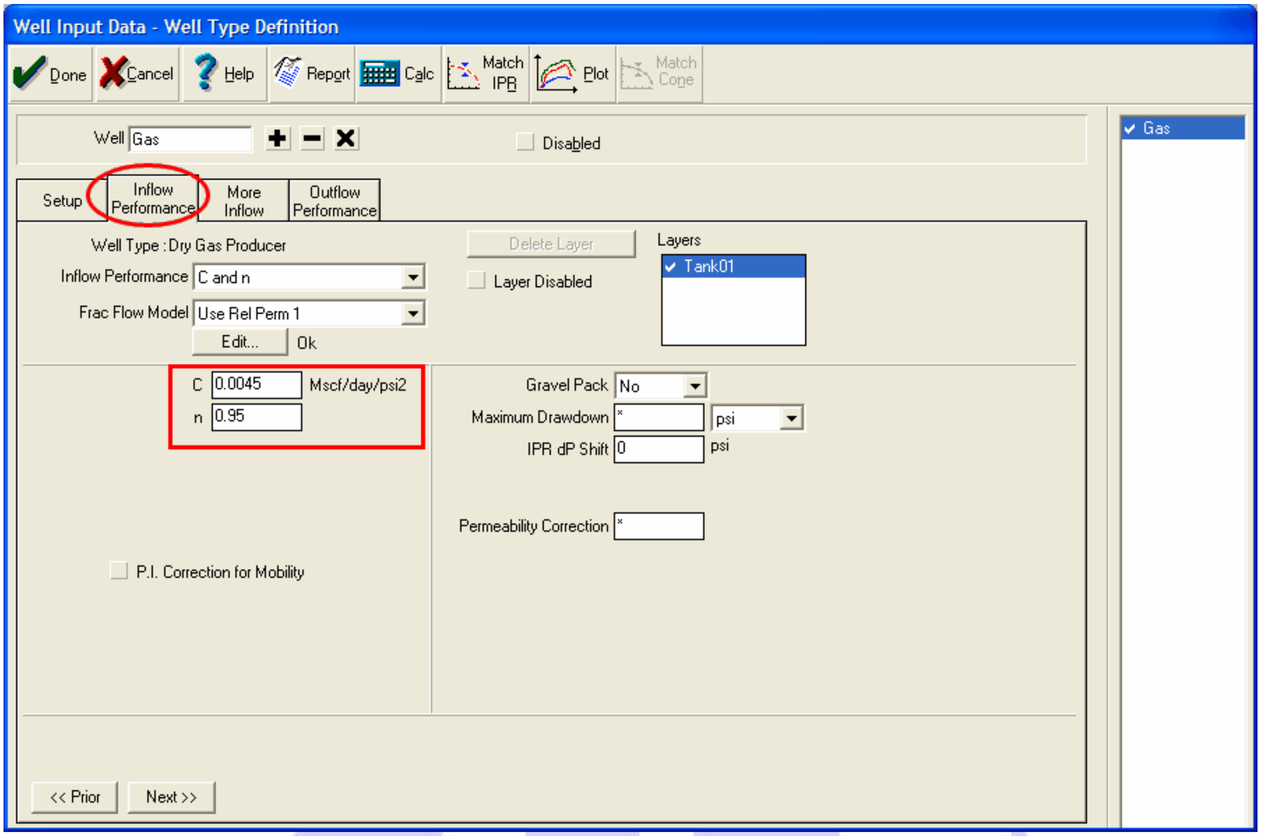
To create a gas producing well, select Production Prediction | Well Type Definition, and set the well type to Dry Gas Producer:


Well Input Data - Well Parameters
Done
Cancel
Help
Well
Disabled
Setup
Inflow Performance
More Inflow
Outflow Performance
<< Prior
Next >>
Validate
✓ Gas

Well: Gas

Well Type: Dry Gas Producer

Click Next to move to the well Inflow Performance input and enter the 'C' and 'n' data:


Well Input Data - Well Type Definition
Done
Cancel
Help
Report
Calc
Match IPR
Plot
Match Cone
Disabled
Setup
Inflow Performance
More Inflow
Outflow Performance
Delete Layer
Layers
Layer Disabled
Edit...
<< Prior
Next >>

Well: Gas

Well Type : Dry Gas Producer

Inflow Performance: C and n

Frac Flow Model: Use Rel Perm 1

Ok

C: 0.0045 Mscf/day/psi2

n: 0.95

☐ P.I. Correction for Mobility

Gravel Pack: No

Maximum Drawdown: * psi

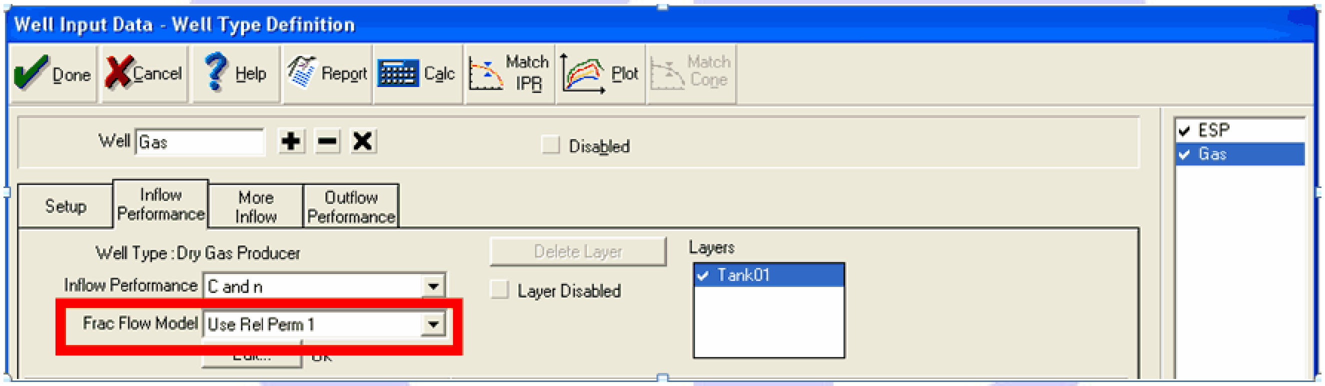
IPR dP Shift: 0 psi

Permeability Correction: *

Layers: ✓ Tank01

✓ Gas

To change the fractional flow model in use, select 'Use Rel Perm 1' in the 'Frac Flow Model' menu:


Well Input Data - Well Type Definition
Done
Cancel
Help
Report
Calc
Match IPR
Plot
Match Cone
Disabled
Setup
Inflow Performance
More Inflow
Outflow Performance
Delete Layer
Layers
Layer Disabled

Well: Gas

Well Type : Dry Gas Producer

Inflow Performance: C and n

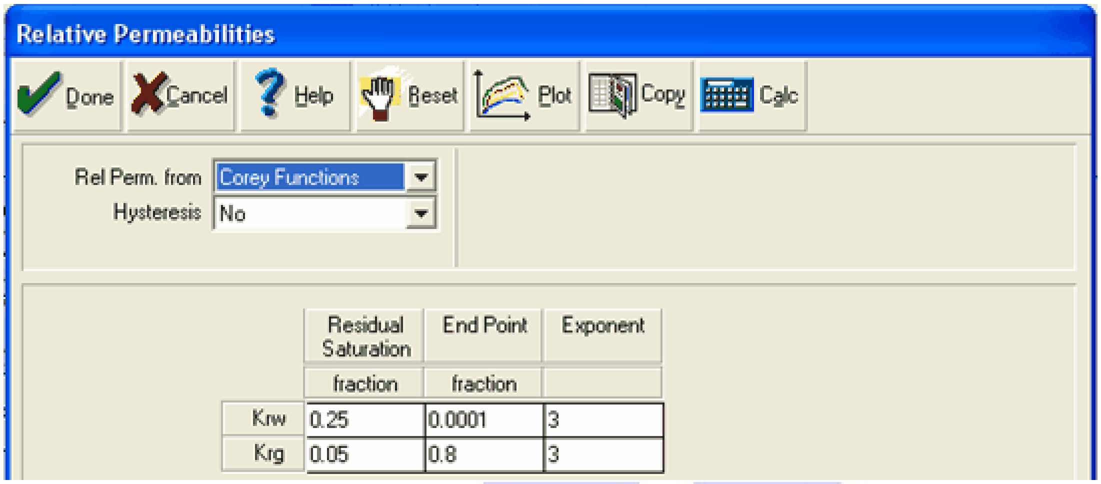
Frac Flow Model: Use Rel Perm 1

Layers: ✓ Tank01

✓ ESP

✓ Gas

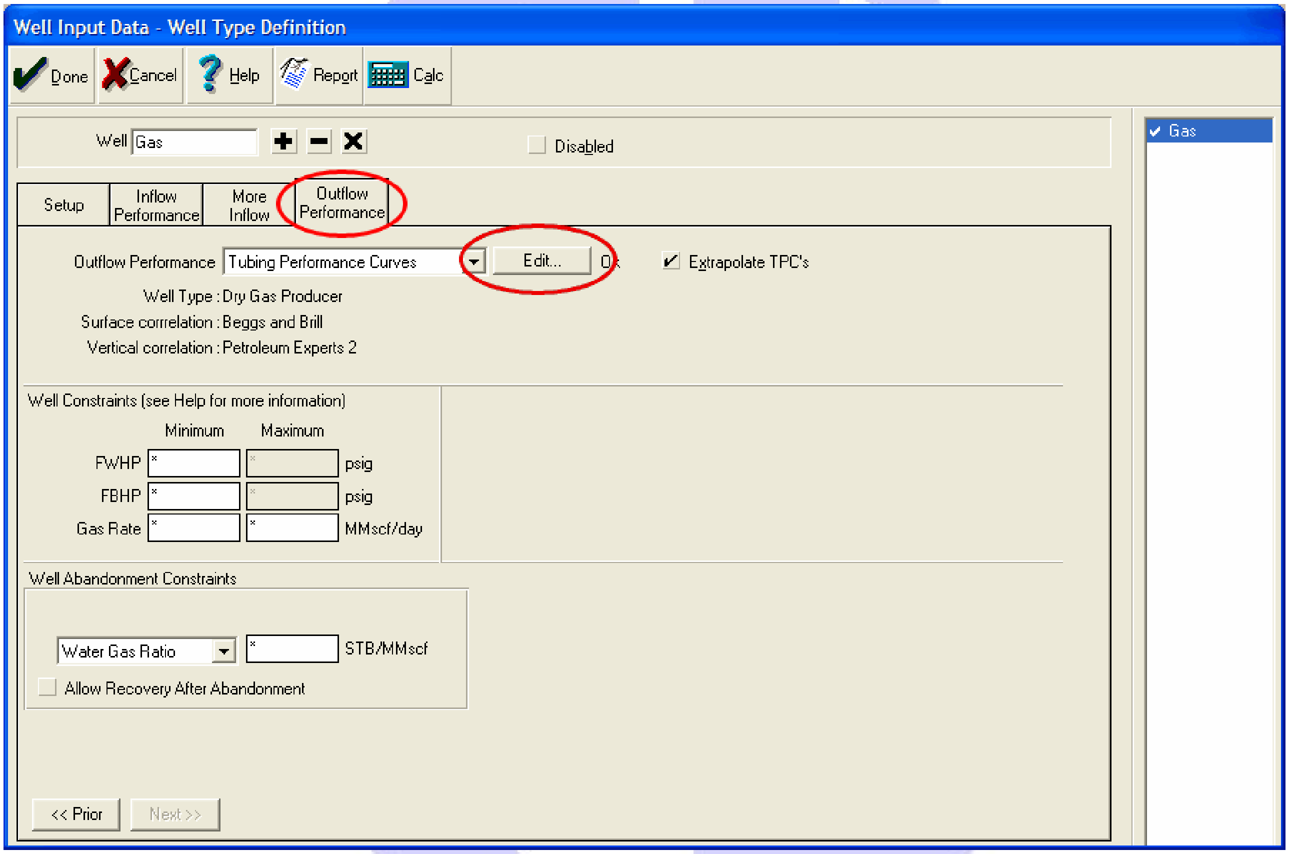
Select 'Edit' to access the blank Relative Permeability table which can be altered to match the table below:


Relative Permeabilities
Done
Cancel
Help
Reset
Plot
Copy
Calc

Rel Perm. from: Corey Functions
Hysteresis: No

	Residual Saturation	End Point	Exponent
	fraction	fraction	
Krw	0.25	0.0001	3
Krg	0.05	0.8	3

Select "Outflow Performance | Edit | Import" to browse for the CBM_GAS_PRODUCER.TPD file that is located in: C:\Program Files\Petroleum Experts\IPM 7.5\Samples\MBAL\CBM:


Well Input Data - Well Type Definition
Done
Cancel
Help
Report
Calc
Setup
Inflow Performance
More Inflow
Outflow Performance
Edit...
<< Prior
Next >>
✓ Gas

Well: Gas

☐ Disabled

Outflow Performance: Tubing Performance Curves

☑ Extrapolate TPC's

Well Type : Dry Gas Producer
Surface correlation : Beggs and Brill
Vertical correlation : Petroleum Experts 2

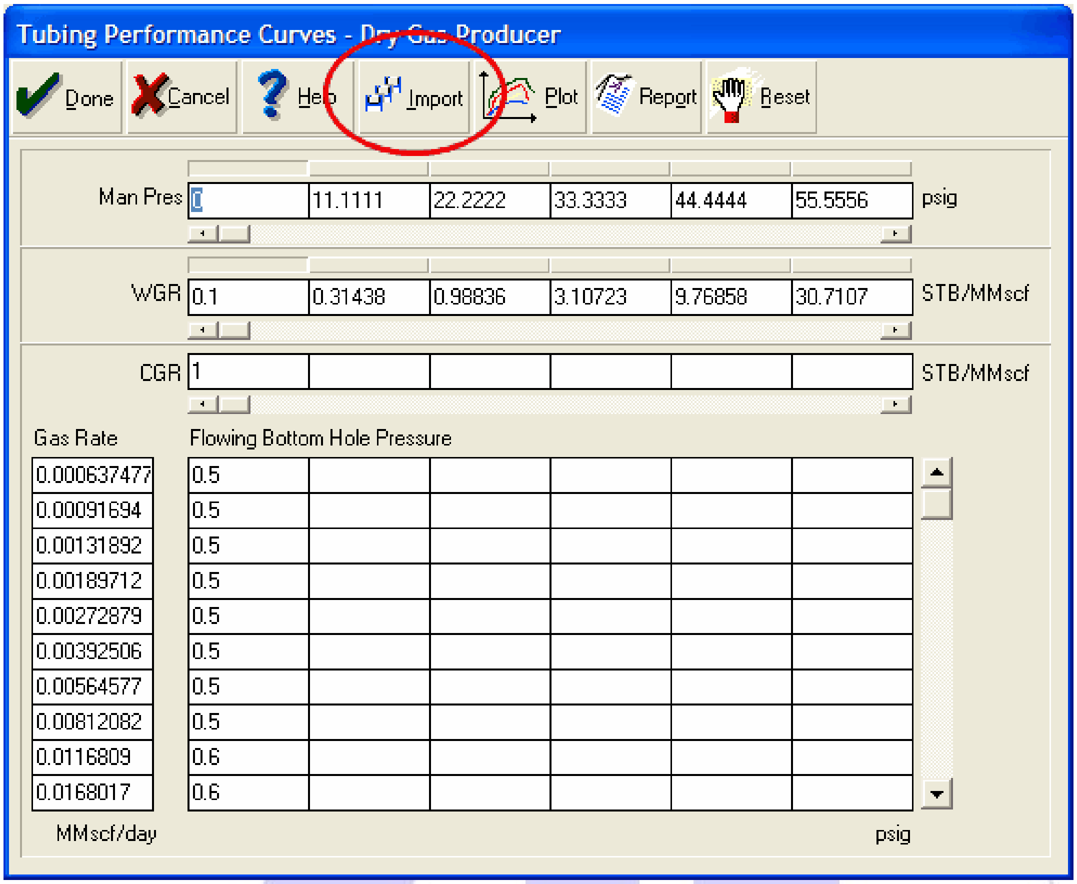
Well Constraints (see Help for more information)

	Minimum	Maximum	
FWHP	*	*	psig
FBHP	*	*	psig
Gas Rate	*	*	MMscf/day

Well Abandonment Constraints

Water Gas Ratio: * STB/MMscf

☐ Allow Recovery After Abandonment


Tubing Performance Curves - Dry Gas Producer
Done
Cancel
Help
Import
Plot
Report
Reset

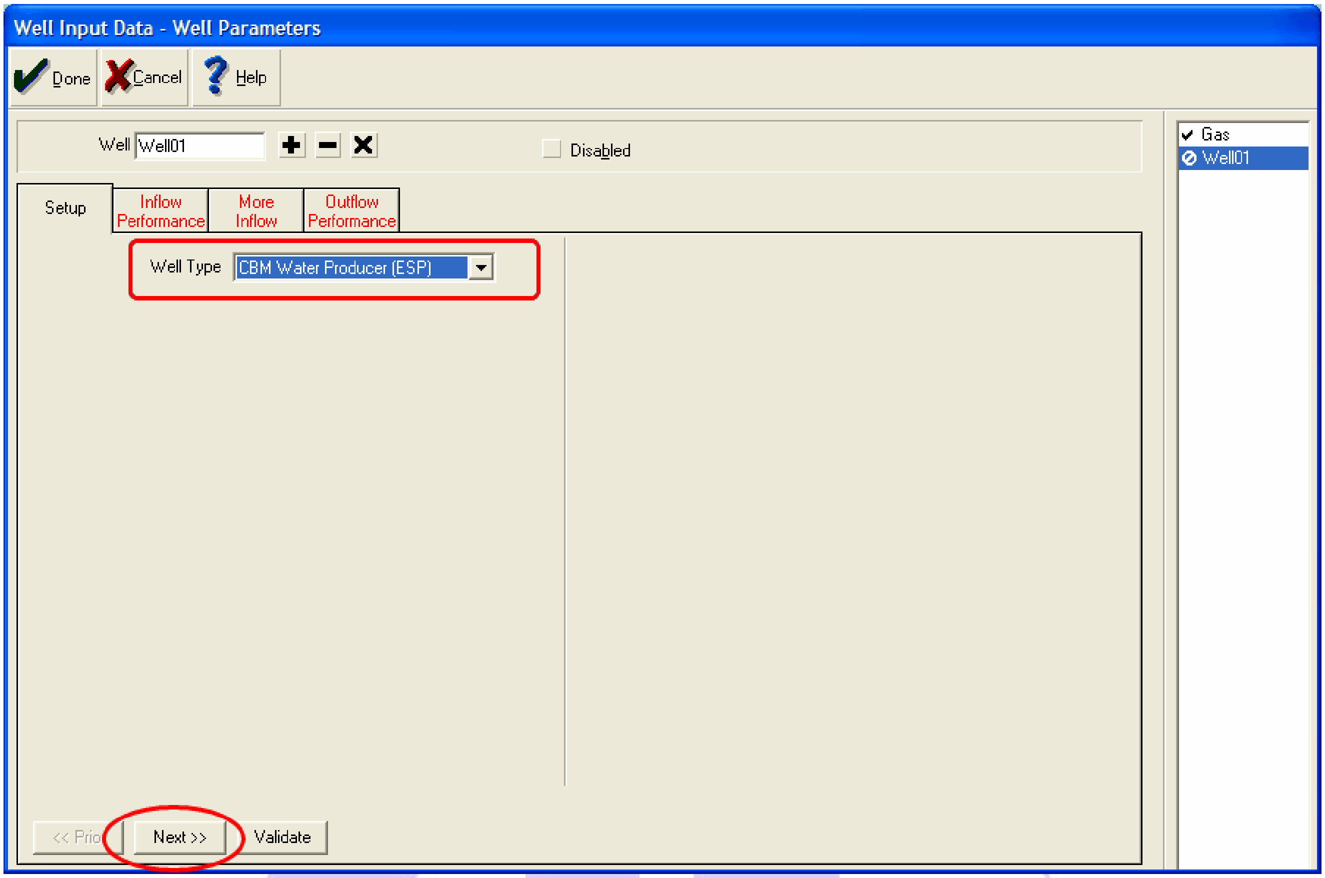
Man Pres	0	11.1111	22.2222	33.3333	44.4444	55.5556	psig
WGR	0.1	0.31438	0.98836	3.10723	9.76858	30.7107	STB/MMscf
CGR	1						STB/MMscf

Gas Rate (MMscf/day)	Flowing Bottom Hole Pressure (psig)					
0.000637477	0.5					
0.00091694	0.5					
0.00131892	0.5					
0.00189712	0.5					
0.00272879	0.5					
0.00392506	0.5					
0.00564577	0.5					
0.00812082	0.5					
0.0116809	0.6					
0.0168017	0.6					

The gas producing well has now been completed.

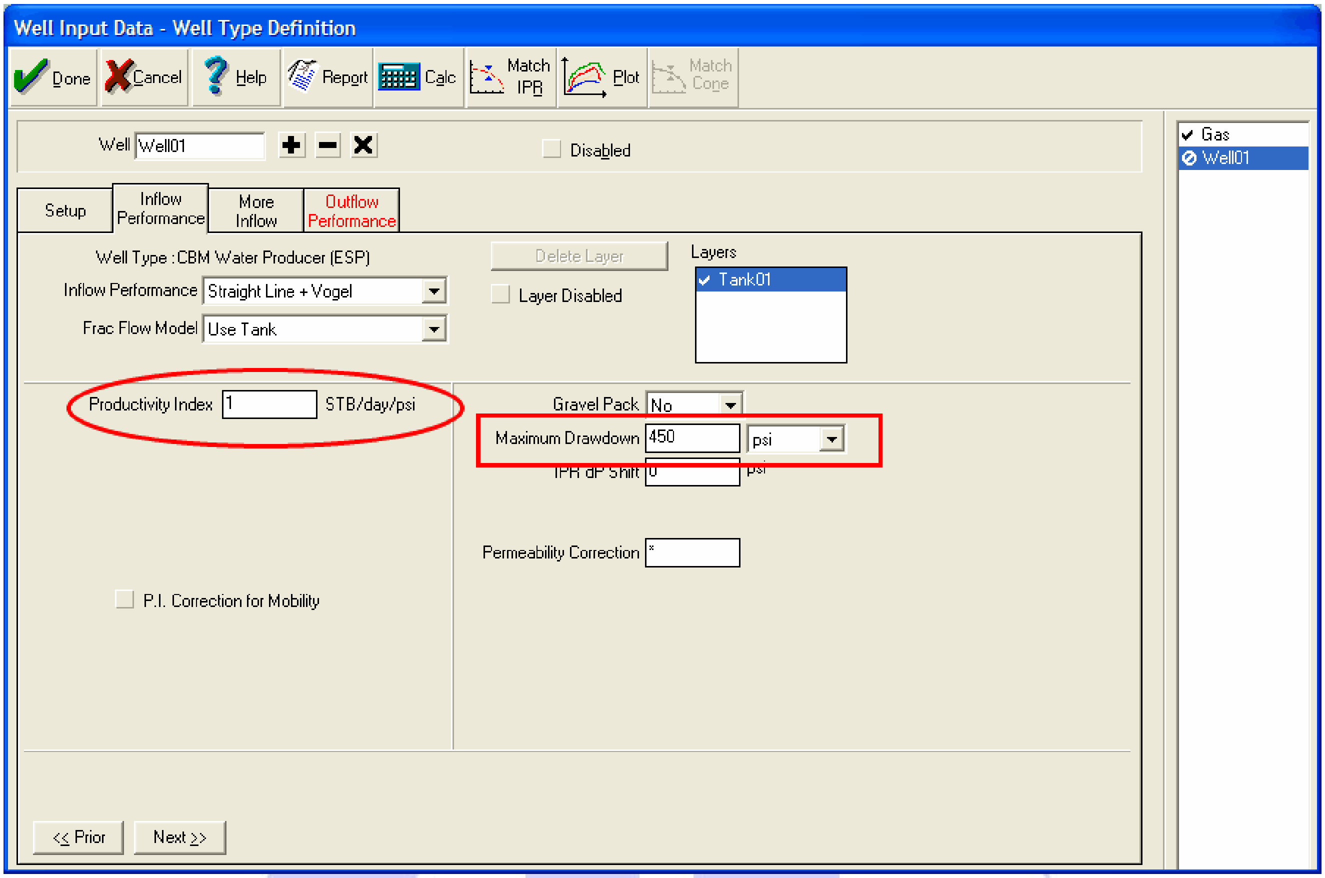
To create the water producing well, from the gas producing well, select the ✚ button from any of the input screens.

Select the well type as CBM Water Producer (ESP):


Well Input Data - Well Parameters
Done
Cancel
Help
Well
Well01
Disabled
Gas
Well01
Setup
Inflow Performance
More Inflow
Outflow Performance
<< Prior
Next >>
Validate

Well Type: CBM Water Producer (ESP)

Select Next to enter the inflow performance data section, and enter the following data:


Well Input Data - Well Type Definition
Done
Cancel
Help
Report
Calc
Match IPR
Plot
Match Cone
Setup
Inflow Performance
More Inflow
Outflow Performance
Delete Layer
<< Prior
Next >>
Gas
Well01

Well: Well01

☐ Disabled

Well Type : CBM Water Producer (ESP)

Inflow Performance: Straight Line + Vogel

Frac Flow Model: Use Tank

☐ Layer Disabled

Layers: ✓ Tank01

Productivity Index: 1 STB/day/psi

Gravel Pack: No

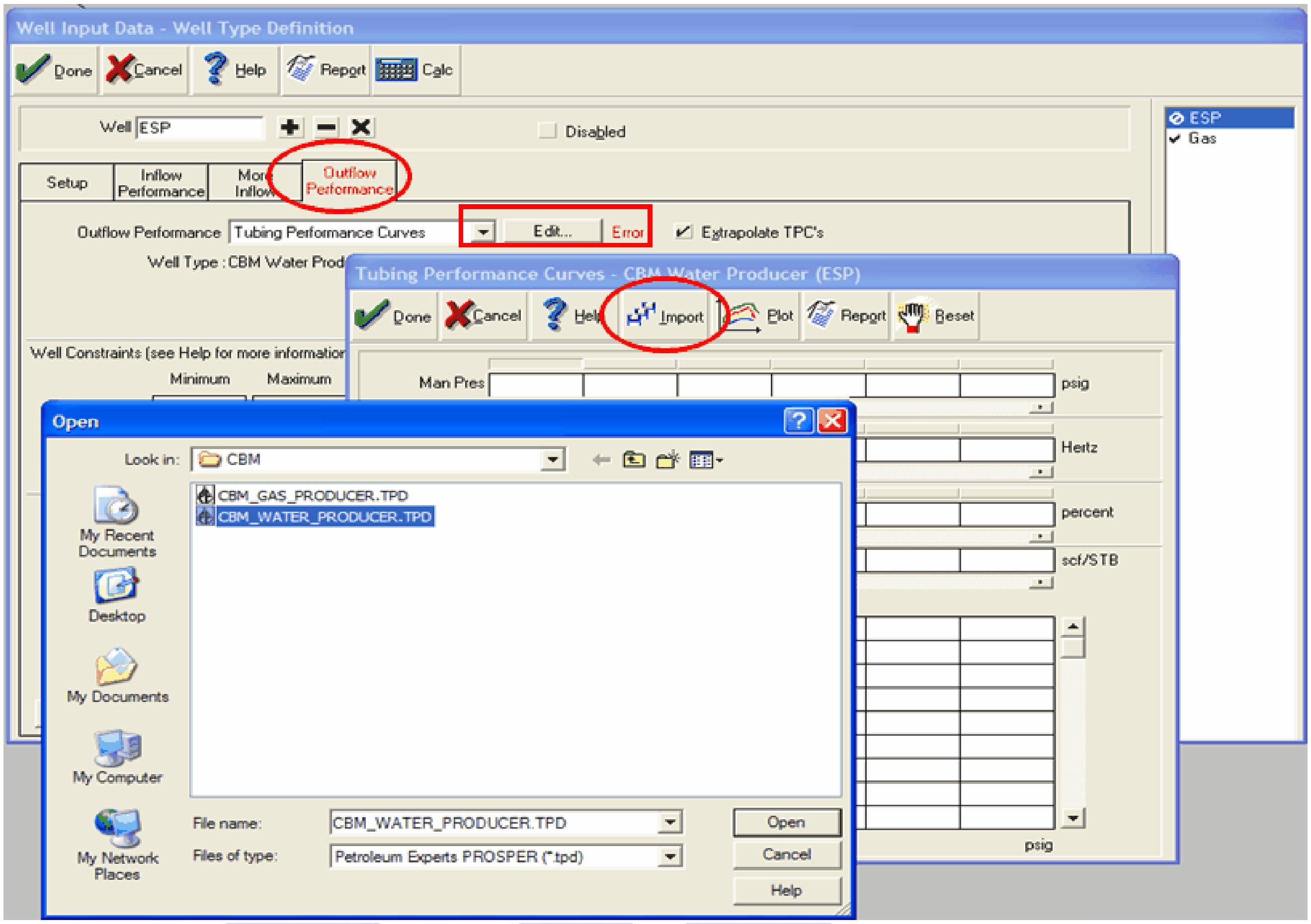
Maximum Drawdown: 450 psi

IPR dP Shift: 0 psi

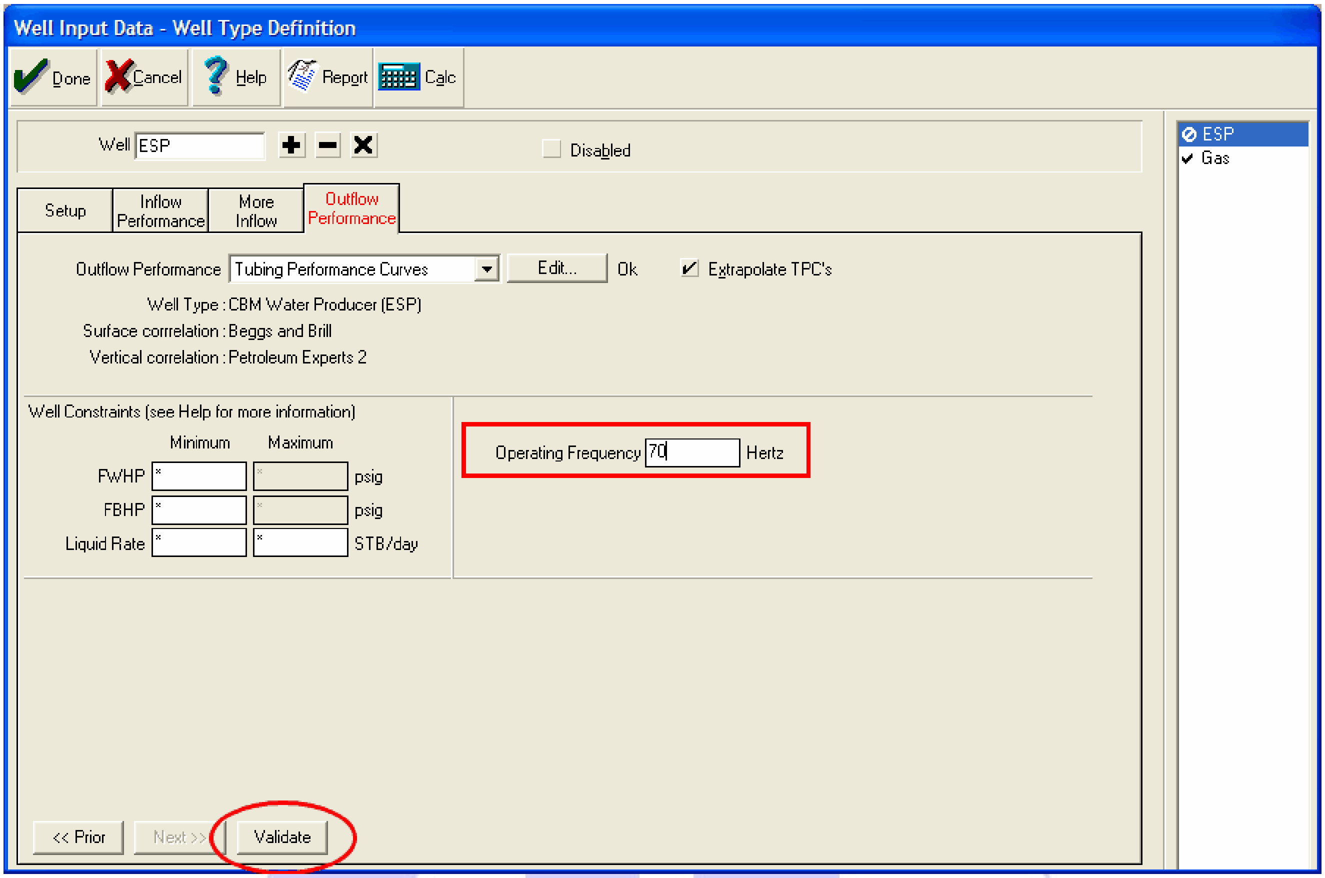
Permeability Correction: *

☐ P.I. Correction for Mobility

Select the Outflow Performance tab (or select Next | Next), then select Edit | Import, to browse for the CBM_WATER_PRODUCER.TPD file:


Well Input Data - Well Type Definition
Done
Cancel
Help
Report
Calc
Well ESP
Disabled
ESP
Gas
Setup
Inflow Performance
More Inflow
Outflow Performance
Outflow Performance Tubing Performance Curves
Edit...
Error
Extrapolate TPC's
Well Type : CBM Water Prod
Well Constraints (see Help for more information
Minimum
Maximum
Tubing Performance Curves - CBM Water Producer (ESP)
Import
Plot
Reset
Man Pres
psig
Hertz
percent
scf/STB
Open
Look in: CBM
My Recent Documents
Desktop
My Documents
My Computer
My Network Places
CBM_GAS_PRODUCER.TPD
CBM_WATER_PRODUCER.TPD
File name: CBM_WATER_PRODUCER.TPD
Files of type: Petroleum Experts PROSPER (*.tpd)
Open
Cancel
Help

From the well Outflow Performance section, enter the ESP operating frequency value:


Done
Cancel
Help
Report
Calc
Setup
Inflow Performance
More Inflow
Outflow Performance
Edit...
<< Prior
Next >>
Validate

Well Input Data - Well Type Definition

Well ESP

☐ Disabled

Outflow Performance: Tubing Performance Curves — Ok

☑ Extrapolate TPC's

Well Type : CBM Water Producer (ESP)

Surface correlation : Beggs and Brill

Vertical correlation : Petroleum Experts 2

Well Constraints (see Help for more information)

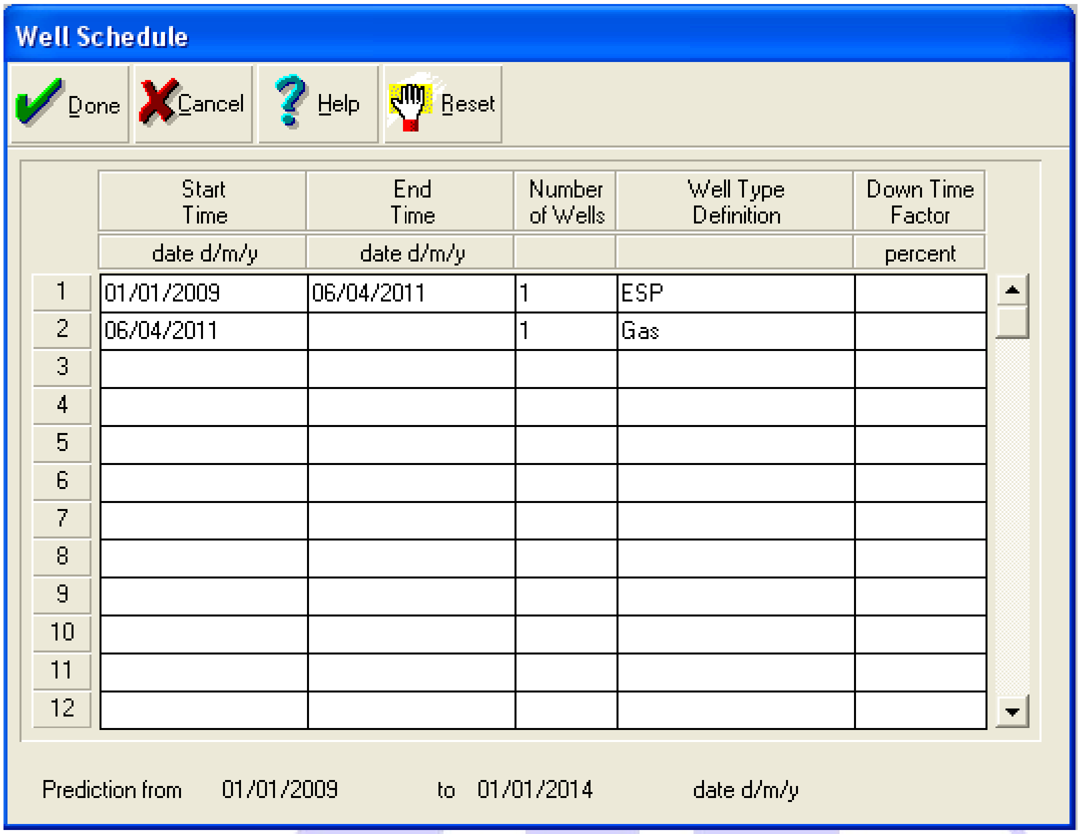
	Minimum	Maximum	
FWHP	*	*	psig
FBHP	*	*	psig
Liquid Rate	*	*	STB/day

Operating Frequency 70 Hertz

ESP
✓ Gas

Now we need to set up the well schedule. The well schedule section provides a means to understand when the de-watering phase can stop (shut-in the ESP) and to start the gas production well.

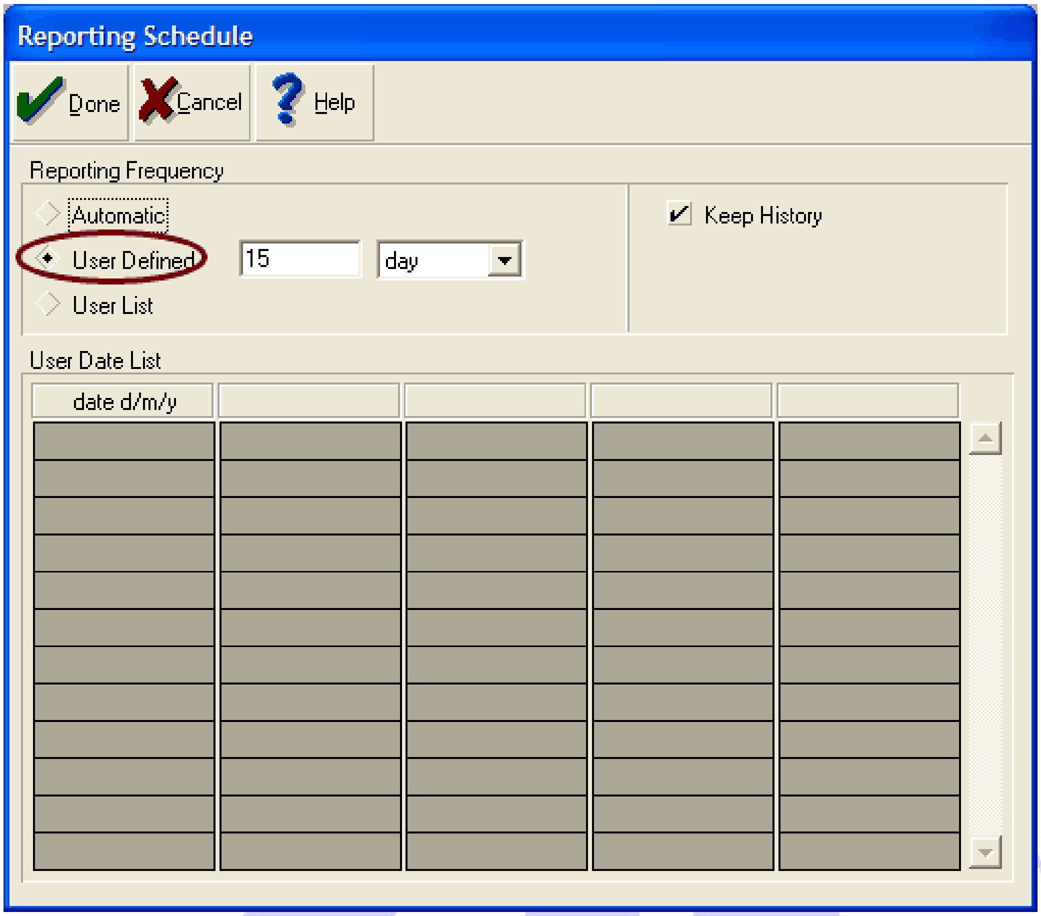
To do this, select Production Prediction | Well Schedule and enter the following data:



	Start Time	End Time	Number of Wells	Well Type Definition	Down Time Factor
	date d/m/y	date d/m/y			percent
1	01/01/2009	06/04/2011	1	ESP	
2	06/04/2011		1	Gas	
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					

Prediction from 01/01/2009 to 01/01/2014 date d/m/y

The Reporting Schedule needs to be completed. Select Production Prediction | Reporting Schedule and select the following options:



Reporting Schedule

Reporting Frequency

○ Automatic

● User Defined 15 day

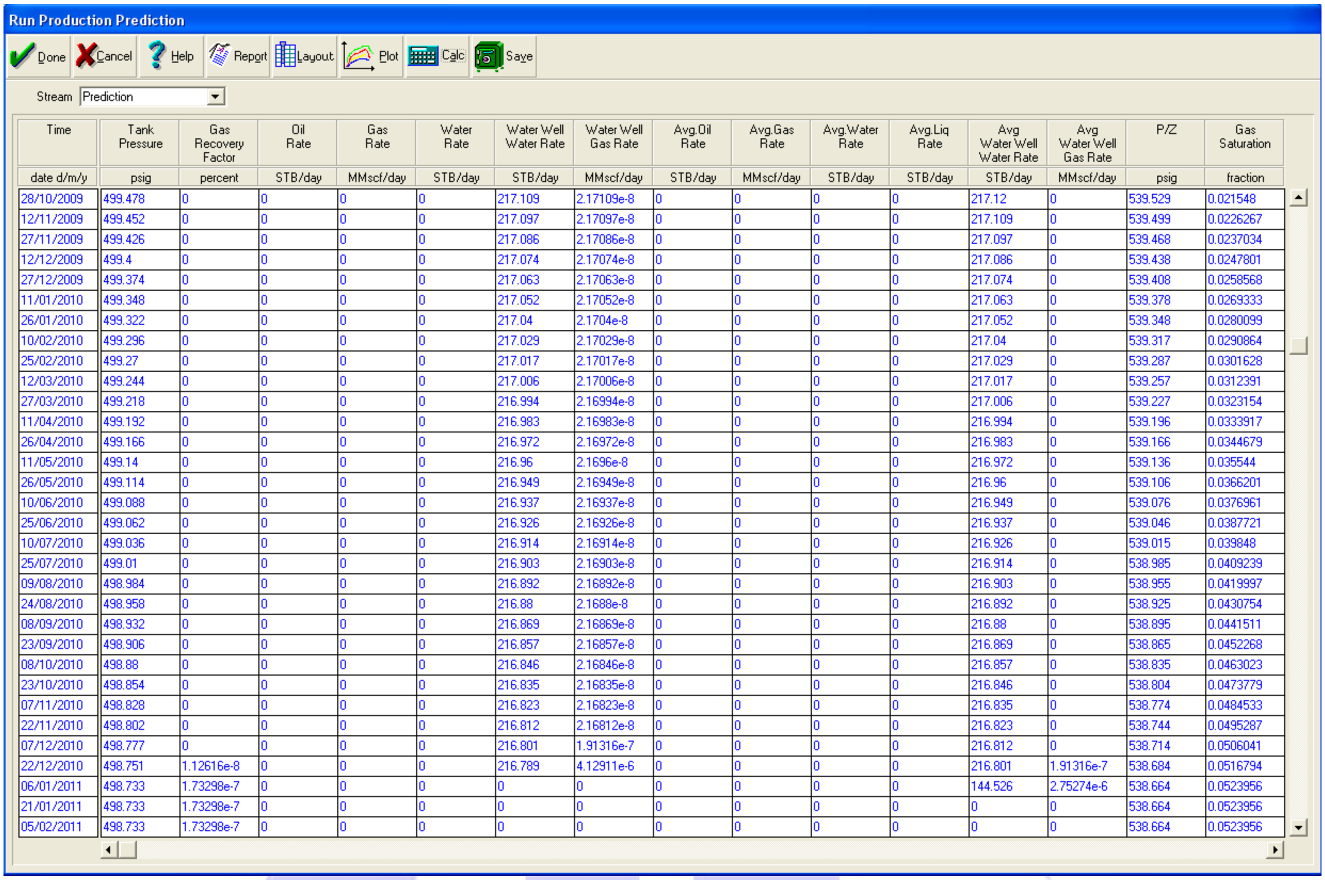
○ User List

☑ Keep History

User Date List

date d/m/y

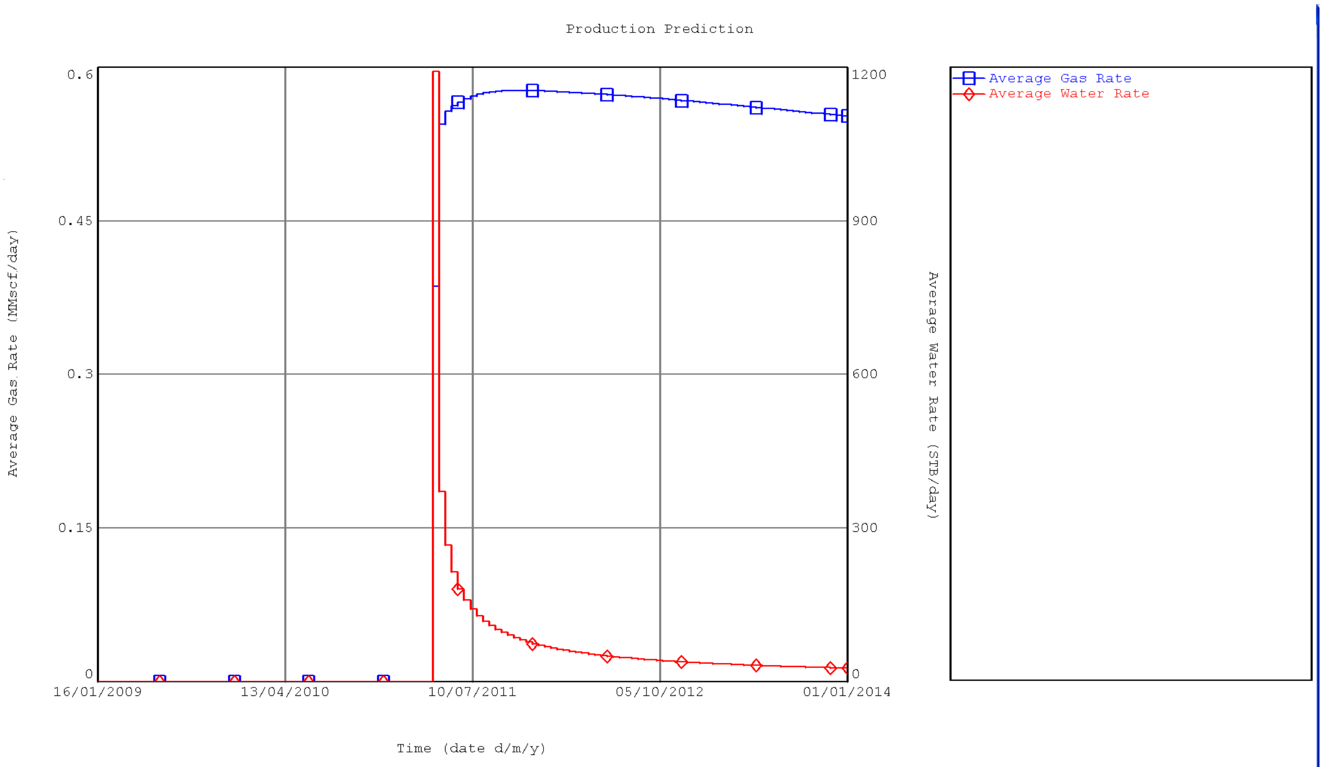
Having carried out all the steps above, the model is now ready to run in forecasting mode. The "Run Prediction" option can now be selected:



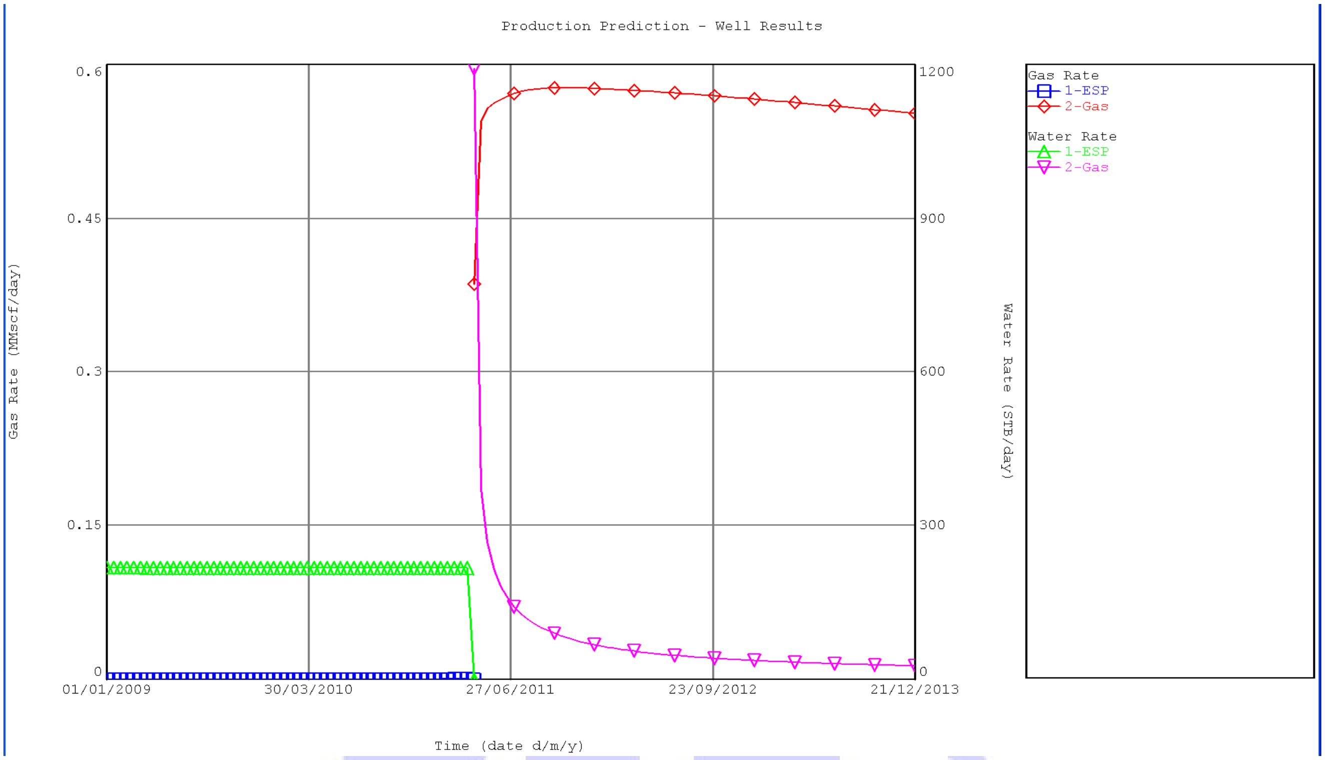
Stream Prediction

Time	Tank Pressure	Gas Recovery Factor	Oil Rate	Gas Rate	Water Rate	Water Well Water Rate	Water Well Gas Rate	Avg.Oil Rate	Avg.Gas Rate	Avg.Water Rate	Avg.Liq Rate	Avg Water Well Water Rate	Avg Water Well Gas Rate	P/Z	Gas Saturation
date d/m/y	psig	percent	STB/day	MMscf/day	STB/day	STB/day	MMscf/day	STB/day	MMscf/day	STB/day	STB/day	STB/day	MMscf/day	psig	fraction
28/10/2009	499.478	0	0	0	0	217.109	2.17109e-8	0	0	0	0	217.12	0	539.529	0.021548
12/11/2009	499.452	0	0	0	0	217.097	2.17097e-8	0	0	0	0	217.109	0	539.499	0.0226267
27/11/2009	499.426	0	0	0	0	217.086	2.17086e-8	0	0	0	0	217.097	0	539.468	0.0237034
12/12/2009	499.4	0	0	0	0	217.074	2.17074e-8	0	0	0	0	217.086	0	539.438	0.0247801
27/12/2009	499.374	0	0	0	0	217.063	2.17063e-8	0	0	0	0	217.074	0	539.408	0.0258568
11/01/2010	499.348	0	0	0	0	217.052	2.17052e-8	0	0	0	0	217.063	0	539.378	0.0269333
26/01/2010	499.322	0	0	0	0	217.04	2.1704e-8	0	0	0	0	217.052	0	539.348	0.0280099
10/02/2010	499.296	0	0	0	0	217.029	2.17029e-8	0	0	0	0	217.04	0	539.317	0.0290864
25/02/2010	499.27	0	0	0	0	217.017	2.17017e-8	0	0	0	0	217.029	0	539.287	0.0301628
12/03/2010	499.244	0	0	0	0	217.006	2.17006e-8	0	0	0	0	217.017	0	539.257	0.0312391
27/03/2010	499.218	0	0	0	0	216.994	2.16994e-8	0	0	0	0	217.006	0	539.227	0.0323154
11/04/2010	499.192	0	0	0	0	216.983	2.16983e-8	0	0	0	0	216.994	0	539.196	0.0333917
26/04/2010	499.166	0	0	0	0	216.972	2.16972e-8	0	0	0	0	216.983	0	539.166	0.0344679
11/05/2010	499.14	0	0	0	0	216.96	2.1696e-8	0	0	0	0	216.972	0	539.136	0.035544
26/05/2010	499.114	0	0	0	0	216.949	2.16949e-8	0	0	0	0	216.96	0	539.106	0.0366201
10/06/2010	499.088	0	0	0	0	216.937	2.16937e-8	0	0	0	0	216.949	0	539.076	0.0376961
25/06/2010	499.062	0	0	0	0	216.926	2.16926e-8	0	0	0	0	216.937	0	539.046	0.0387721
10/07/2010	499.036	0	0	0	0	216.914	2.16914e-8	0	0	0	0	216.926	0	539.015	0.039848
25/07/2010	499.01	0	0	0	0	216.903	2.16903e-8	0	0	0	0	216.914	0	538.985	0.0409239
09/08/2010	498.984	0	0	0	0	216.892	2.16892e-8	0	0	0	0	216.903	0	538.955	0.0419997
24/08/2010	498.958	0	0	0	0	216.88	2.1688e-8	0	0	0	0	216.892	0	538.925	0.0430754
08/09/2010	498.932	0	0	0	0	216.869	2.16869e-8	0	0	0	0	216.88	0	538.895	0.0441511
23/09/2010	498.906	0	0	0	0	216.857	2.16857e-8	0	0	0	0	216.869	0	538.865	0.0452268
08/10/2010	498.88	0	0	0	0	216.846	2.16846e-8	0	0	0	0	216.857	0	538.835	0.0463023
23/10/2010	498.854	0	0	0	0	216.835	2.16835e-8	0	0	0	0	216.846	0	538.804	0.0473779
07/11/2010	498.828	0	0	0	0	216.823	2.16823e-8	0	0	0	0	216.835	0	538.774	0.0484533
22/11/2010	498.802	0	0	0	0	216.812	2.16812e-8	0	0	0	0	216.823	0	538.744	0.0495287
07/12/2010	498.777	0	0	0	0	216.801	1.91316e-7	0	0	0	0	216.812	0	538.714	0.0506041
22/12/2010	498.751	1.12616e-8	0	0	0	216.789	4.12911e-6	0	0	0	0	216.801	1.91316e-7	538.684	0.0516794
06/01/2011	498.733	1.73298e-7	0	0	0	0	0	0	0	0	0	144.526	2.75274e-6	538.664	0.0523956
21/01/2011	498.733	1.73298e-7	0	0	0	0	0	0	0	0	0	0	0	538.664	0.0523956
05/02/2011	498.733	1.73298e-7	0	0	0	0	0	0	0	0	0	0	0	538.664	0.0523956

Select Plot, and plot for instance the tank Average Water and Gas rates:



Selecting Production Prediction | Well Results, the well production signatures can be plotted:



This step marks the end of the CBM example.

3.4 Tight Gas Example

This example will define the steps required to carry out matching to historical data for a tight gas model and then use the matched data to perform a prediction.

It has been assumed that the user is familiar with the basic functions in **MBAL**, in particular, the Material Balance Tool.

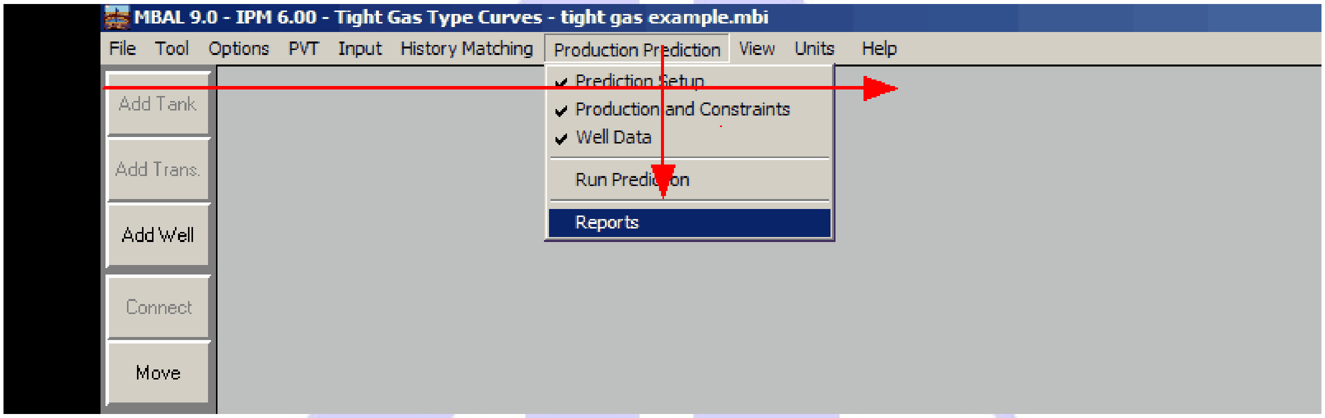
As with the material balance tool, the objective of the Tight Gas tool is to provide the user with a methodology for estimating the GIIP in a particular situation for which classical material balance is not applicable.

Due to tight gas reservoirs having long transient periods, classical material balance calculations would be carried out with difficulty upon them.

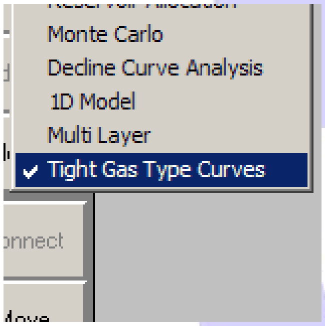
Analysis can instead be performed on the flowing bottom hole pressure measurements in a similar fashion to well test analysis in order to determine the effective radius of the reservoir.

The GIIP can be estimated from the: reservoir geometry, thickness and porosity with the use of volumetric calculations.

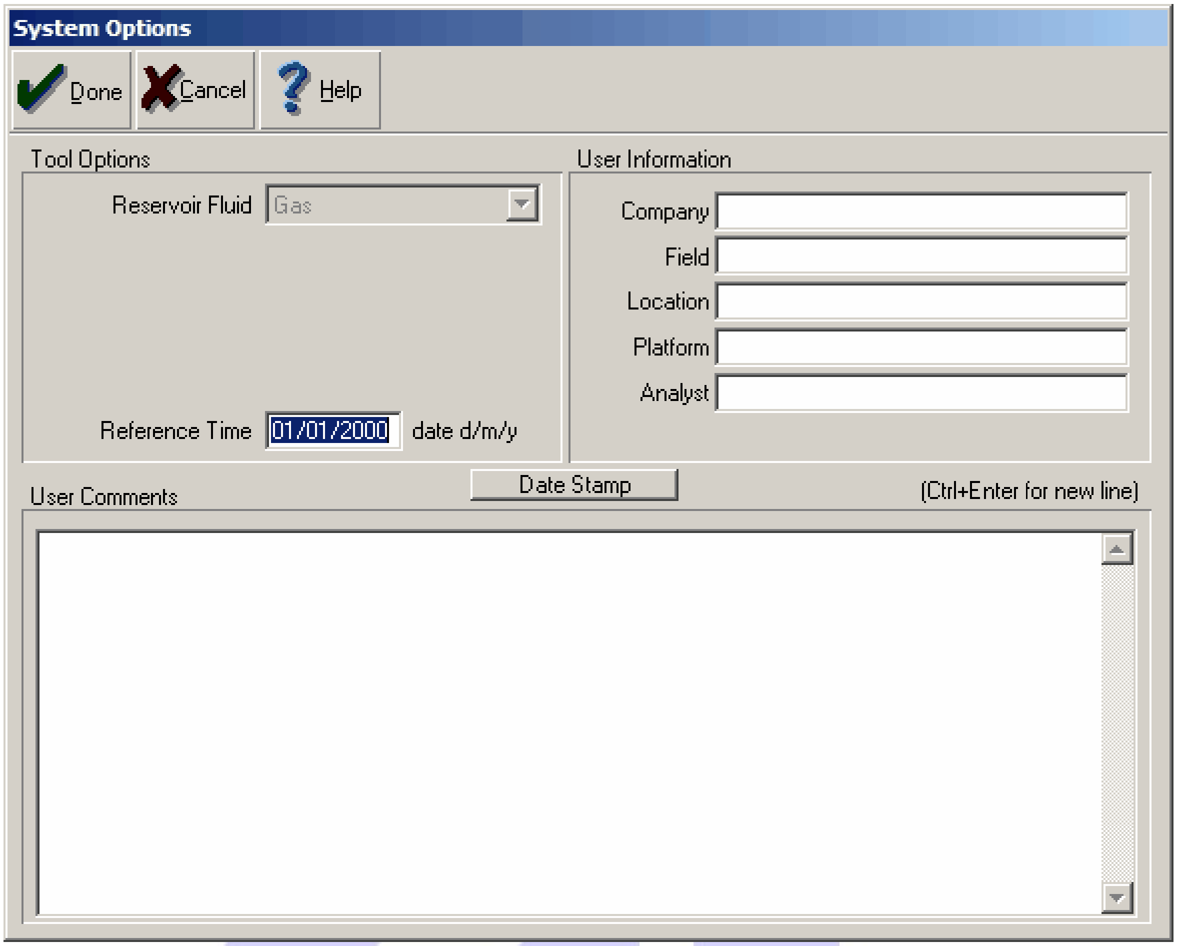
As with the other tools in **MBAL**, the menu is structured so that the user can follow the options from left to right and top to bottom:


MBAL 9.0 - IPM 6.00 - Tight Gas Type Curves - tight gas example.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Add Tank
Add Trans.
Add Well
Connect
Move
Prediction Setup
Production and Constraints
Well Data
Run Prediction
Reports

For this example, the Tool will be chosen as the 'Tight Gas Type Curves':


Monte Carlo
Decline Curve Analysis
1D Model
Multi Layer
Tight Gas Type Curves

The Options for this case are fixed to the fluid relevant to this model so the user will not be making any alterations to the defaults here.



System Options
Done
Cancel
Help
Tool Options
User Information

Reservoir Fluid: Gas

Company:

Field:

Location:

Platform:

Analyst:

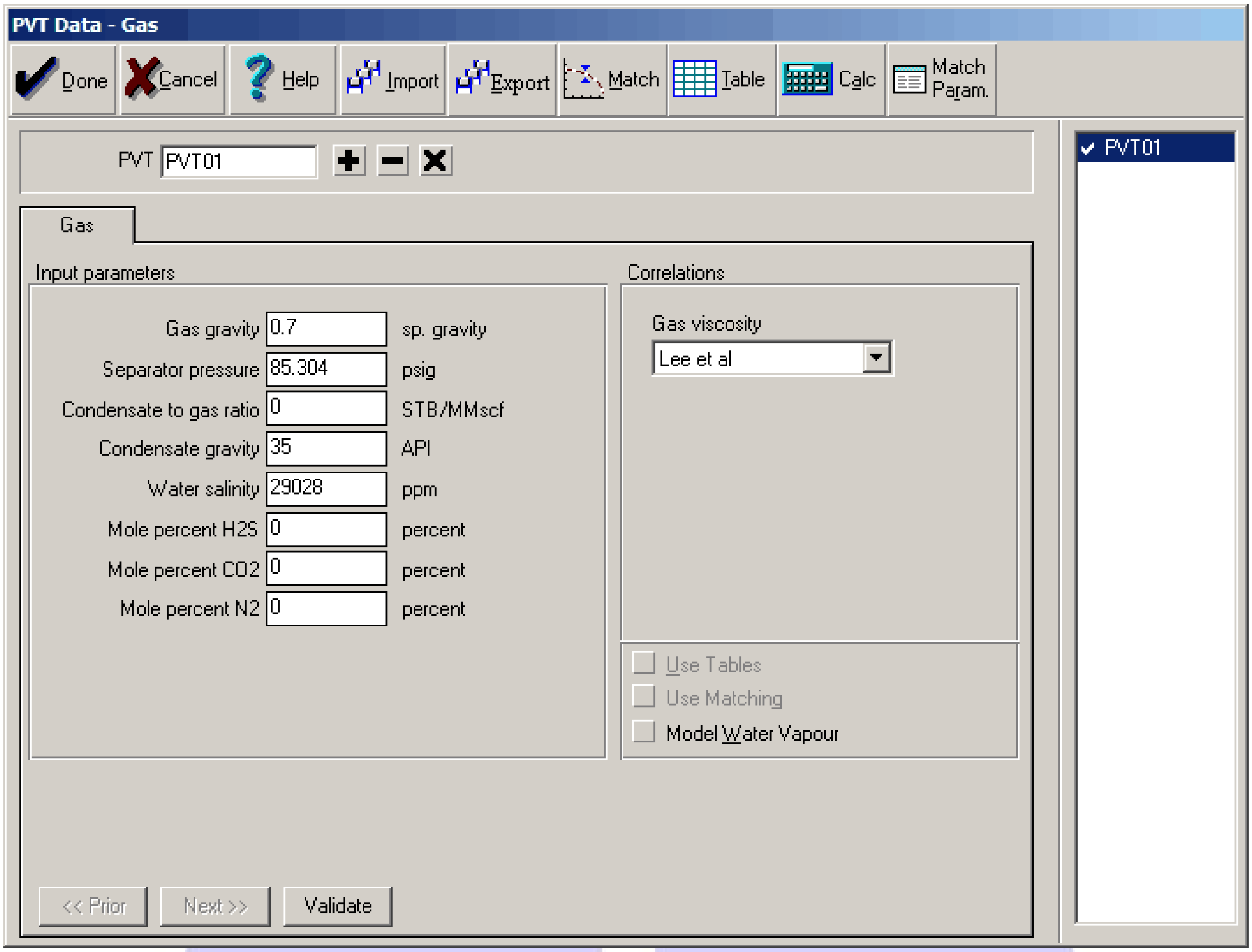
Reference Time: 01/01/2000 date d/m/y

User Comments
Date Stamp
(Ctrl+Enter for new line)

The rest of the options will be explained in the following chapters.

3.4.1 PVT Definition

The PVT screen for this model is identical to the dry gas PVT screen of the material balance tool. The following information can be entered:


PVT Data - Gas
Done
Cancel
Help
Import
Export
Match
Table
Calc
Match Param.
PVT01
Gas
Input parameters
Correlations
<< Prior
Next >>
Validate

PVT: PVT01

Gas gravity: 0.7 sp. gravity
Separator pressure: 85.304 psig
Condensate to gas ratio: 0 STB/MMscf
Condensate gravity: 35 API
Water salinity: 29028 ppm
Mole percent H2S: 0 percent
Mole percent CO2: 0 percent
Mole percent N2: 0 percent

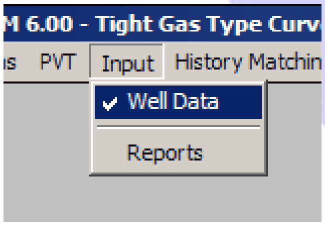
Gas viscosity: Lee et al

☐ Use Tables
☐ Use Matching
☐ Model Water Vapour

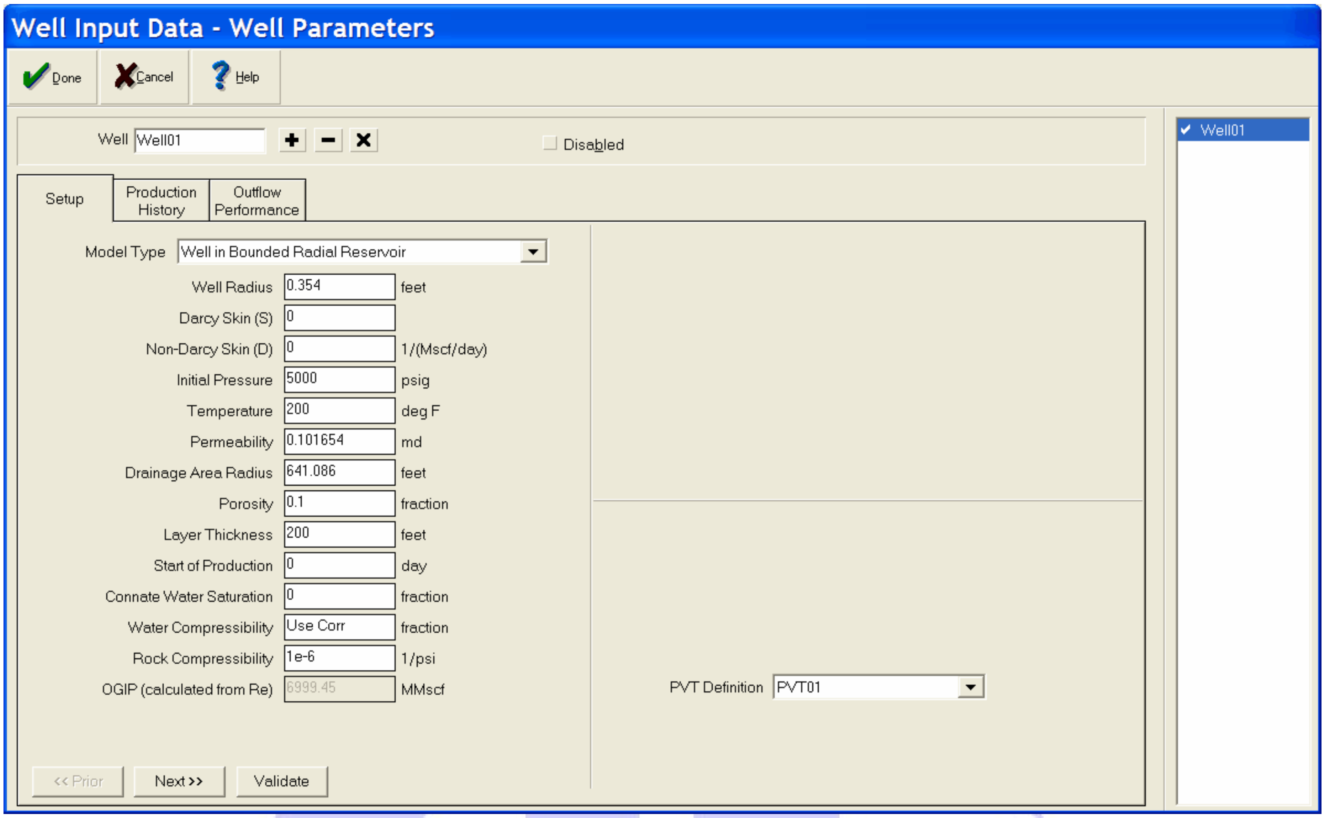
If information relating to the Z-factor, Bg or viscosity of the gas are available, matching could be also carried out. In this example the gas is dry so we assume that the correlations are able to predict the gas properties without requiring any matching.

3.4.2 Input Well Data

The well input data menu is accessed from the Well Data section:


M 6.00 - Tight Gas Type Curv
is
PVT
Input
History Matchin
Well Data
Reports

The following screen will appear:


Well Input Data - Well Parameters
Done
Cancel
Help
+
−
✕
Setup
Production History
Outflow Performance
<< Prior
Next >>
Validate
✔ Well01

Well: Well01

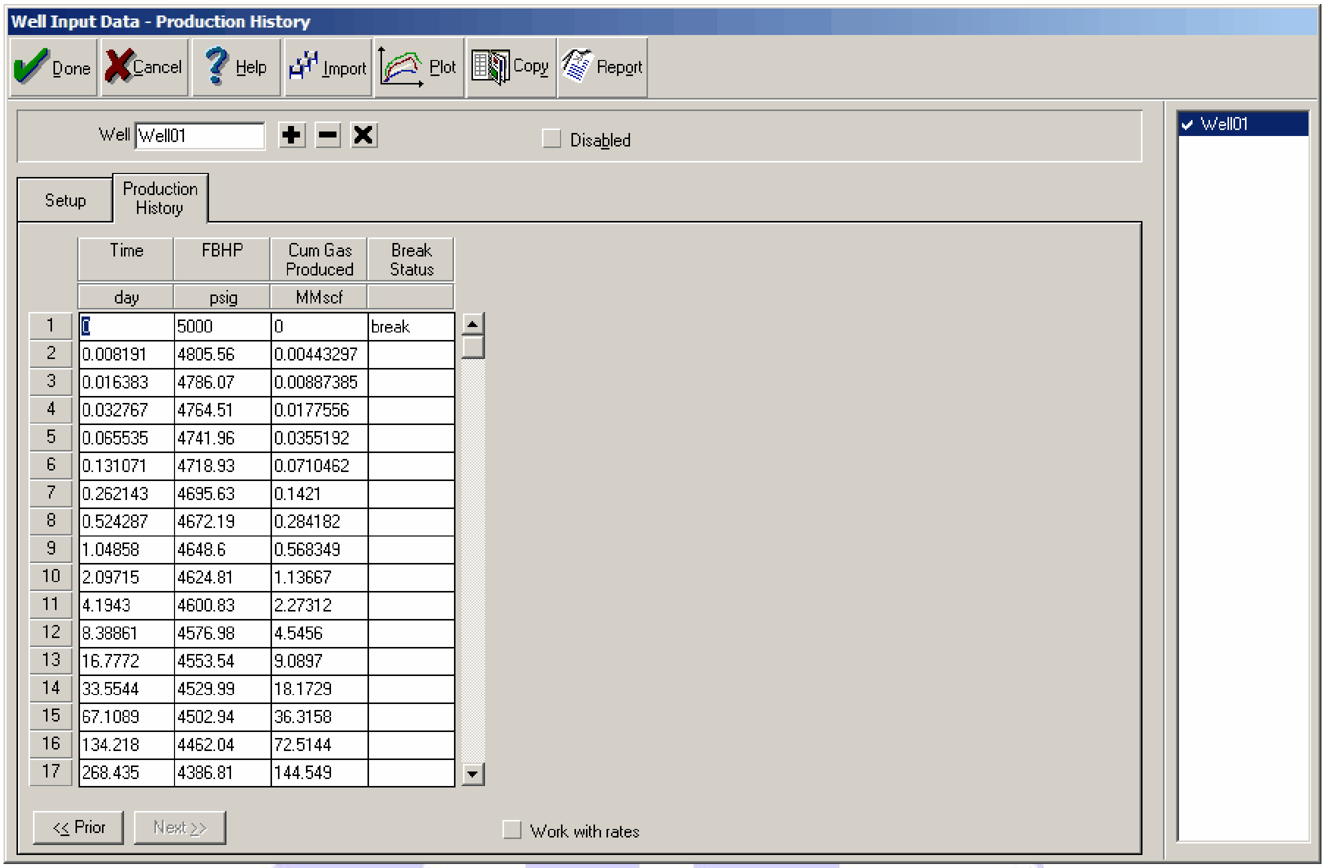
☐ Disabled

Model Type	Well in Bounded Radial Reservoir	
Well Radius	0.354	feet
Darcy Skin (S)	0	
Non-Darcy Skin (D)	0	1/(Mscf/day)
Initial Pressure	5000	psig
Temperature	200	deg F
Permeability	0.101654	md
Drainage Area Radius	641.086	feet
Porosity	0.1	fraction
Layer Thickness	200	feet
Start of Production	0	day
Connate Water Saturation	0	fraction
Water Compressibility	Use Corr	fraction
Rock Compressibility	1e-6	1/psi
OGIP (calculated from Re)	6999.45	MMscf

PVT Definition: PVT01

The information required in the Setup screen is shown screenshot above. Please note that the Radius entered above is an estimate. The Help screen provides more information on the data inputs.

The second screen in the list relates to the production history. The data can be copied and pasted from the Excel Spreadsheet (Tight Gas Data.xls) provided in the **MBAL** Tight Gas Example directory:


Well Input Data - Production History
Done
Cancel
Help
Import
Plot
Copy
Report
Setup
Production History
<< Prior
Next >>
Well01

Well Well01

☐ Disabled

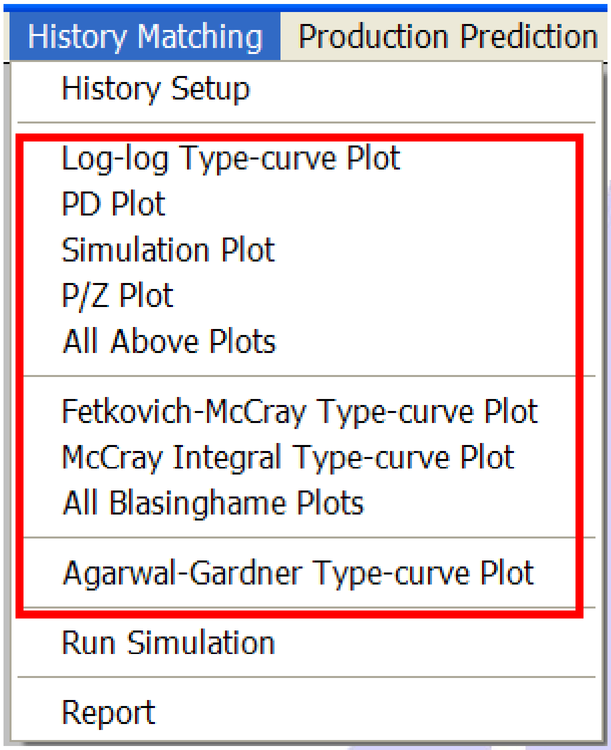
	Time	FBHP	Cum Gas Produced	Break Status
	day	psig	MMscf	
1	0	5000	0	break
2	0.008191	4805.56	0.00443297	
3	0.016383	4786.07	0.00887385	
4	0.032767	4764.51	0.0177556	
5	0.065535	4741.96	0.0355192	
6	0.131071	4718.93	0.0710462	
7	0.262143	4695.63	0.1421	
8	0.524287	4672.19	0.284182	
9	1.04858	4648.6	0.568349	
10	2.09715	4624.81	1.13667	
11	4.1943	4600.83	2.27312	
12	8.38861	4576.98	4.5456	
13	16.7772	4553.54	9.0897	
14	33.5544	4529.99	18.1729	
15	67.1089	4502.94	36.3158	
16	134.218	4462.04	72.5144	
17	268.435	4386.81	144.549	

☐ Work with rates

This is entered as FBHP Vs Cumulative gas production.

3.4.3 History Matching

The history matching can be carried out in a variety of ways:


History Matching
Production Prediction
History Setup
Log-log Type-curve Plot
PD Plot
Simulation Plot
P/Z Plot
All Above Plots
Fetkovich-McCray Type-curve Plot
McCray Integral Type-curve Plot
All Blasinghame Plots
Agarwal-Gardner Type-curve Plot
Run Simulation
Report

There are two main blocks of plots in the screen above, the first relating to the classical Type Curve Plot. The second block relates to the Blasinghame Plots

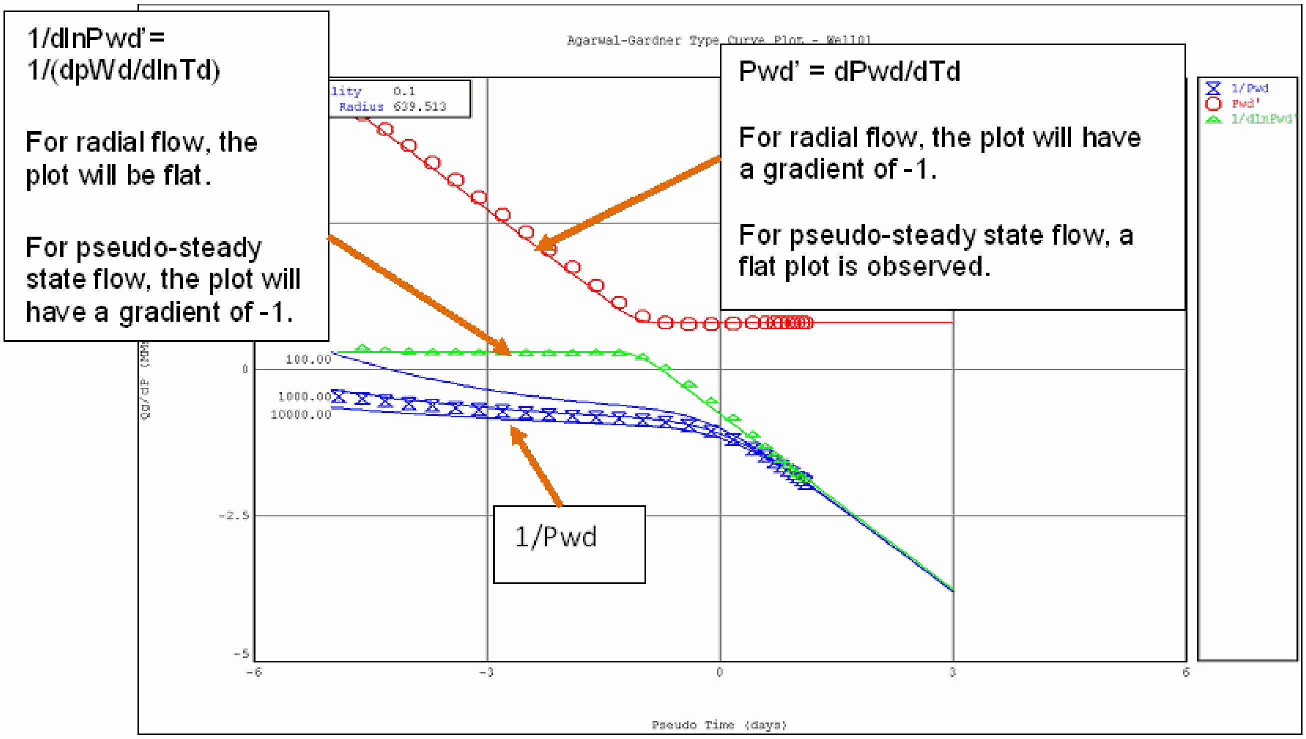
The Agarwal-Gardner Type Curve Plot is also included and is based on the following paper: Agarwal, Gardner, Kelinsteiber and Fussel, *Analyzin Well Production using Combined Type Curve and Decline Curve Analysis Concepts*. This method is applied to transient systems for which measurable reservoir pressures would be unavailable, so wellbore pressures would instead be required.

the resulting plot shows three forms of dimensionless pressure plotted on the y-axis:

- 1/Pwd
- 1/dlnPwd' = 1/(dPwd/dlnTd)
- Pwd' = dPwd/dTd

Where: Pwd = (k.h.dm(p))/(1422.T.Q)

when carrying our a match on the plot, the vertical match defines the permeability, while the match along the horizontal axis defines the distance to the boundary.


Agarwal-Gardner Type Curve Plot - Well01
lity 0.1
Radius 639.513
1/Pwd
Pwd'
1/dlnPwd'
Qg/dP (MM
100.00
1000.00
10000.00
0
-2.5
-5
-6
-3
0
3
6
Pseudo Time (days)

1/dlnPwd'= 1/(dpWd/dlnTd)

For radial flow, the plot will be flat.

For pseudo-steady state flow, the plot will have a gradient of -1.

Pwd' = dPwd/dTd

For radial flow, the plot will have a gradient of -1.

For pseudo-steady state flow, a flat plot is observed.

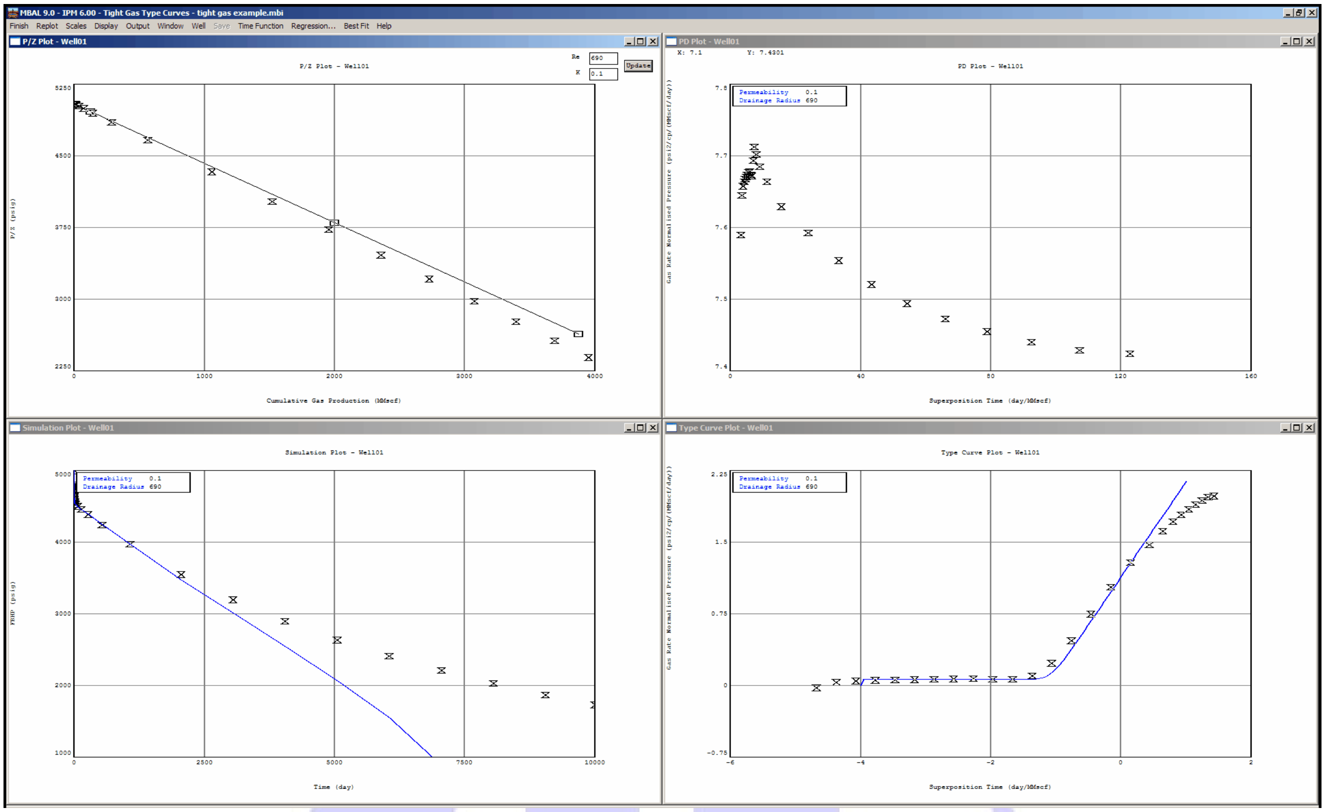
1/Pwd

Due to the different match point which the Pwd' plot has with respect to the other plots, attempting to match all three at the same time could become very complex. To overcome this issue, it is possible to match them individually by selecting: *Match On*, from the plot screen that allows each plot to be selected and matched individually.

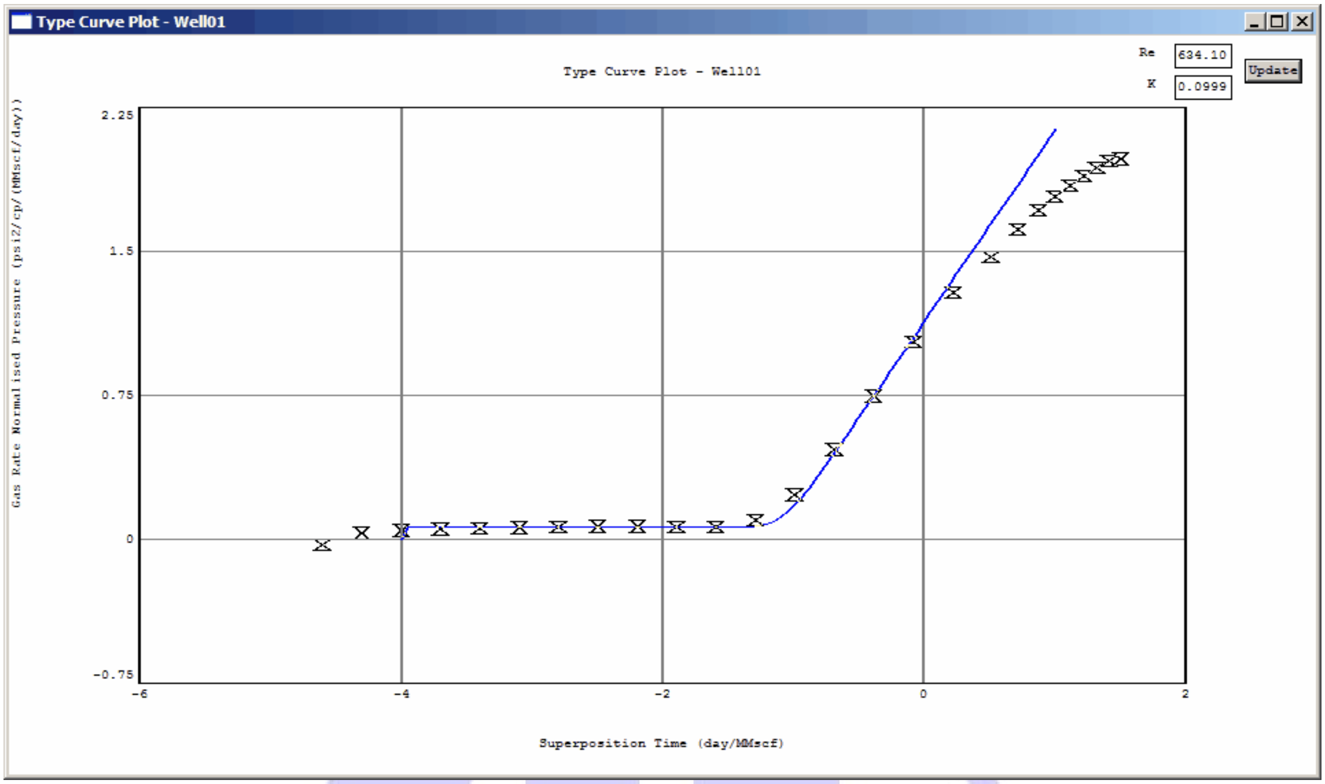
the time function in use is the same as the Blasinghame type-curve as defined in *Tight Gas History Fetkovich-McCray Plot*.

Type curves showing fractured wells are also available.

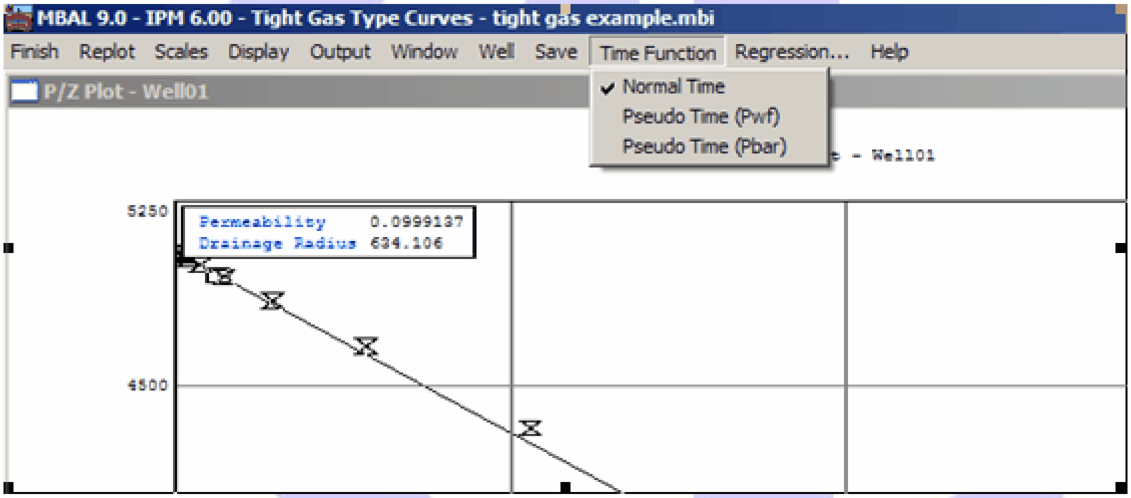
For this example, we will be using the Type Curve Plot for the history matching. Choosing the option to see all the plots:


MBAL 9.0 - IPM 6.00 - Tight Gas Type Curves - tight gas example.mbi
Finish Replot Scales Display Output Window Well Save Time Function Regression... Best Fit Help
P/Z Plot - Well01
P/Z Plot - Well01
Re 690
K 0.1
Update
P/Z (psig)
Cumulative Gas Production (MMscf)
PD Plot - Well01
X: 7.1 Y: 7.4301
PD Plot - Well01
Permeability 0.1
Drainage Radius 690
Gas Rate Normalized Pressure (psi2/cp/(MMscf/day))
Superposition Time (day/MMscf)
Simulation Plot - Well01
Simulation Plot - Well01
Permeability 0.1
Drainage Radius 690
FBHP (psig)
Time (day)
Type Curve Plot - Well01
Type Curve Plot - Well01
Permeability 0.1
Drainage Radius 690
Gas Rate Normalized Pressure (psi2/cp/(MMscf/day))
Superposition Time (day/MMscf)

If we highlight the Type Curve plot, we can hold down the Shift button on the keyboard and at the same time click the left mouse button and move the mouse around in the screen. This will move the data until we can fit the type curve as closely as possible. Shifting the plot up or down changes the K and shifting it left or right changes the Reservoir Radius (re).

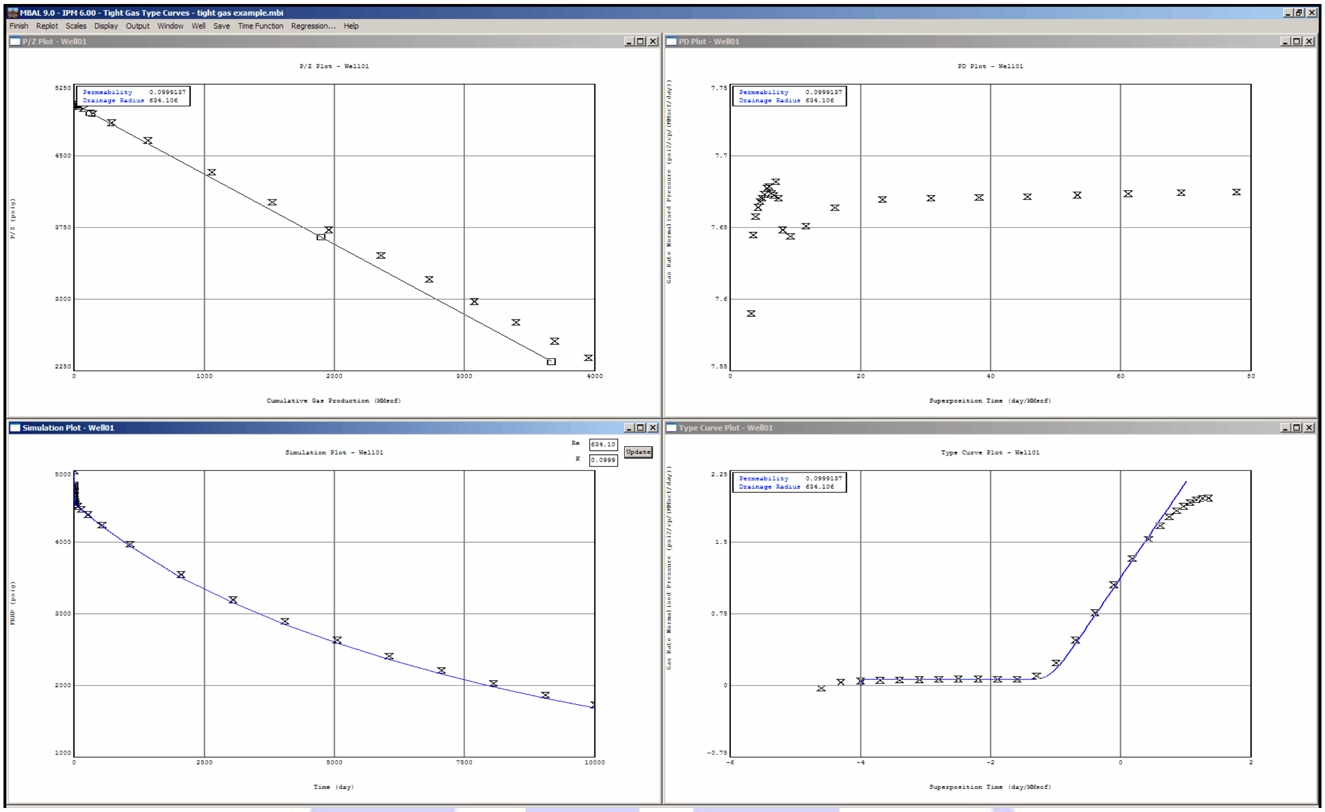

Type Curve Plot - Well01
Re 634.10
K 0.0999
Update
Type Curve Plot - Well01
Gas Rate Normalised Pressure (psi2/cp/(MMscf/day))
2.25
1.5
0.75
0
-0.75
-6
-4
-2
0
2
Superposition Time (day/MMscf)

Simultaneously, the other plots will also change.


MBAL 9.0 - IPM 6.00 - Tight Gas Type Curves - tight gas example.mbi
Finish
Replot
Scales
Display
Output
Window
Well
Save
Time Function
Regression...
Help
✓ Normal Time
Pseudo Time (Pwf)
Pseudo Time (Pbar)
P/Z Plot - Well01
- Well01
5250
4500

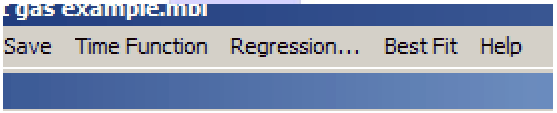
Permeability 0.0999137
Drainage Radius 634.106

We can then see that the simulation plot can reproduce the trend of the data better:


MBAL 9.0 - IPM 6.00 - Tight Gas Type Curves - tight gas example.mbi
Finish Replot Scales Display Output Window Well Save Time Function Regression... Help
P/Z Plot - Well01
P/Z Plot - Well01
Permeability 0.0999137
Drainage Radius 634.106
P/Z (psig)
Cumulative Gas Production (MMscf)
PD Plot - Well01
PD Plot - Well01
Gas Rate Normalised Pressure (psi2/cp/(MMscf/day))
Superposition Time (day/MMscf)
Simulation Plot - Well01
Simulation Plot - Well01
Re 634.10
K 0.0999
Update
FBHP (psig)
Time (day)
Type Curve Plot - Well01
Type Curve Plot - Well01
Superposition Time (day/MMscf)

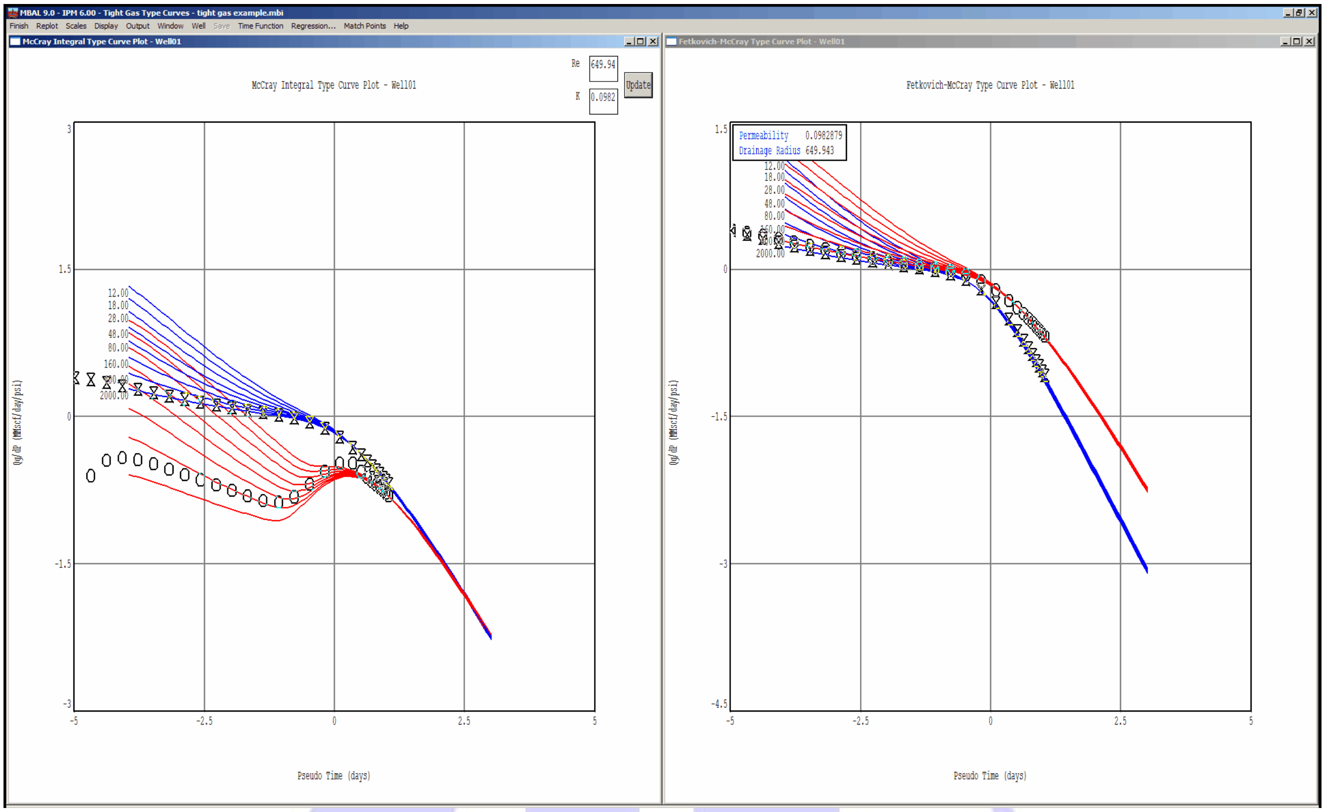
It can also be seen that the P/Z plot changes in accordance, while the Pd plot approaches a straight line shape.

Matching improvements can be achieved by using the *Regression Engine* or best fit options as necessary:


gas example.mbi
Save
Time Function
Regression...
Best Fit
Help

The controls of the regression screen are the same as those of the material balance tool.

As a quality and consistency check, the Blasingham plots can also be used for this case. Since the case is already matched as best as possible, these plots should also already be matched:


MBAL 9.0 - IPM 6.00 - Tight Gas Type Curves - tight gas example.mbi
Finish Replot Scales Display Output Window Well Save Time Function Regression... Match Points Help
McCray Integral Type Curve Plot - Well01
Update
McCray Integral Type Curve Plot - Well01
3
1.5
0
-1.5
-3
-5
-2.5
0
2.5
5
12.00
18.00
28.00
48.00
80.00
160.00
2000.00
(qg/dP (MMscf/day/psi)
Pseudo Time (days)
Fetkovich-McCray Type Curve Plot - Well01
Fetkovich-McCray Type Curve Plot - Well01
1.5
0
-1.5
-3
-4.5
-5
-2.5
0
2.5
5
12.00
18.00
28.00
48.00
80.00
160.00
2000.00
qg/dP (MMscf/day/psi)
Pseudo Time (days)

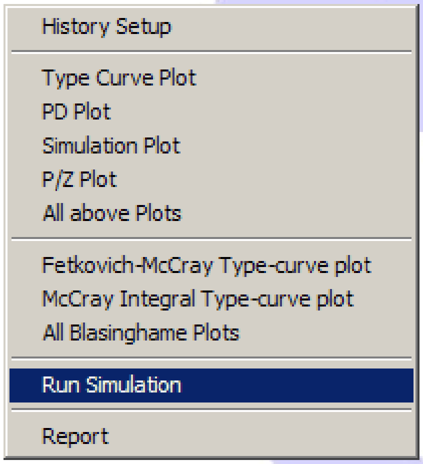
Re 649.94

K 0.0982

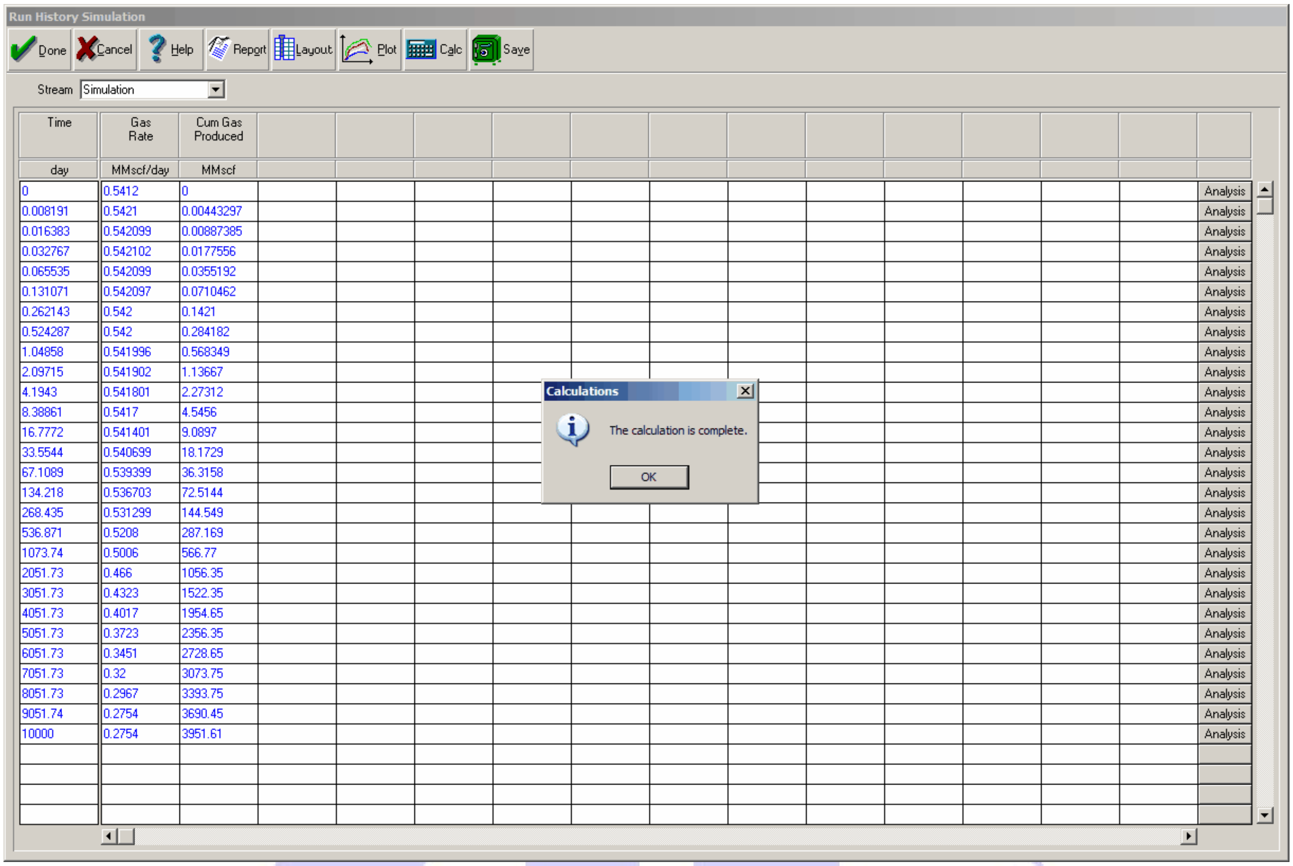
Permeability 0.0982879

Drainage Radius 649.943

The final stage of the History Matching is to perform the Simulation:


History Setup
Type Curve Plot
PD Plot
Simulation Plot
P/Z Plot
All above Plots
Fetkovich-McCray Type-curve plot
McCray Integral Type-curve plot
All Blasingham Plots
Run Simulation
Report

The controls are the same as for the material balance tool:

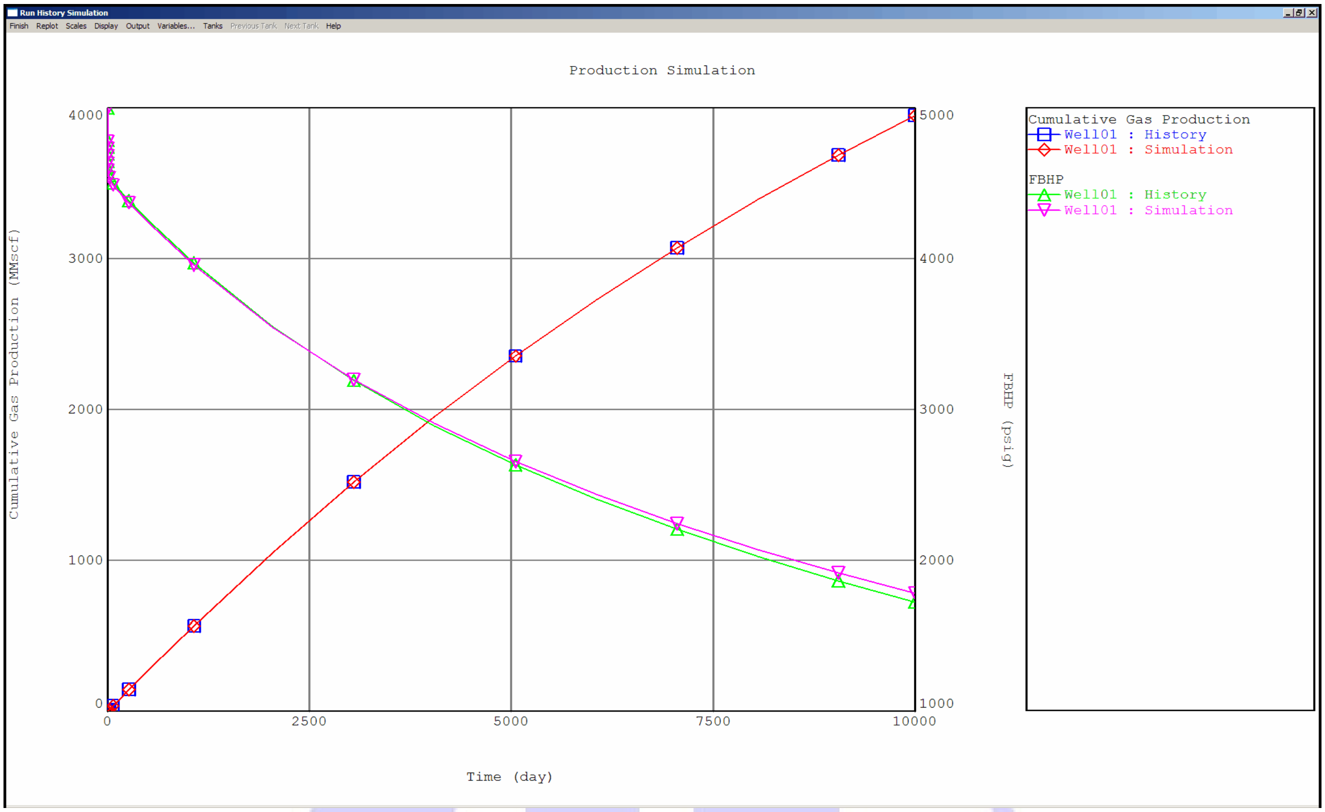


Stream: Simulation

Time day	Gas Rate MMscf/day	Cum Gas Produced MMscf	
0	0.5412	0	Analysis
0.008191	0.5421	0.00443297	Analysis
0.016383	0.542099	0.00887385	Analysis
0.032767	0.542102	0.0177556	Analysis
0.065535	0.542099	0.0355192	Analysis
0.131071	0.542097	0.0710462	Analysis
0.262143	0.542	0.1421	Analysis
0.524287	0.542	0.284182	Analysis
1.04858	0.541996	0.568349	Analysis
2.09715	0.541902	1.13667	Analysis
4.1943	0.541801	2.27312	Analysis
8.38861	0.5417	4.5456	Analysis
16.7772	0.541401	9.0897	Analysis
33.5544	0.540699	18.1729	Analysis
67.1089	0.539399	36.3158	Analysis
134.218	0.536703	72.5144	Analysis
268.435	0.531299	144.549	Analysis
536.871	0.5208	287.169	Analysis
1073.74	0.5006	566.77	Analysis
2051.73	0.466	1056.35	Analysis
3051.73	0.4323	1522.35	Analysis
4051.73	0.4017	1954.65	Analysis
5051.73	0.3723	2356.35	Analysis
6051.73	0.3451	2728.65	Analysis
7051.73	0.32	3073.75	Analysis
8051.73	0.2967	3393.75	Analysis
9051.74	0.2754	3690.45	Analysis
10000	0.2754	3951.61	Analysis

The calculation is complete.

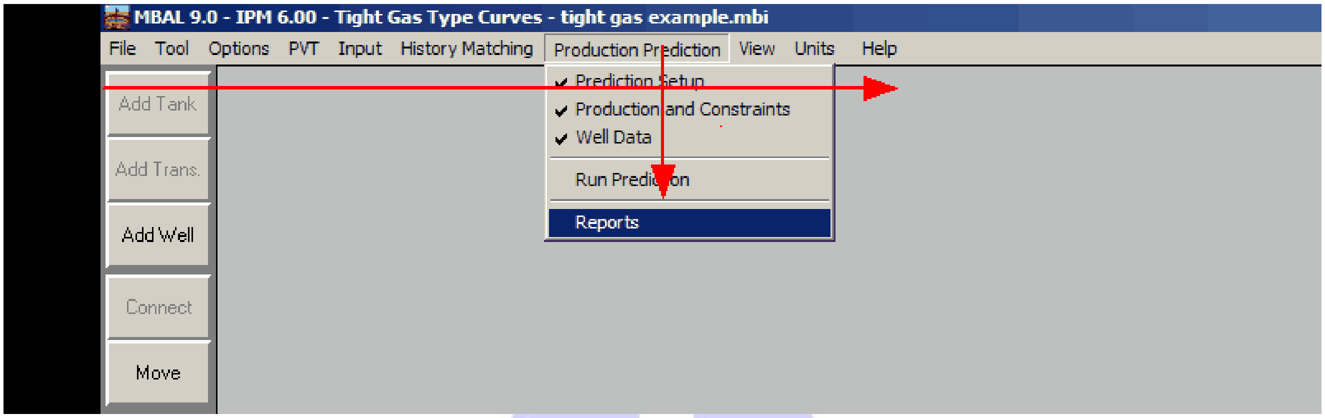
The calculated variable in the simulation plot is the FBHP:



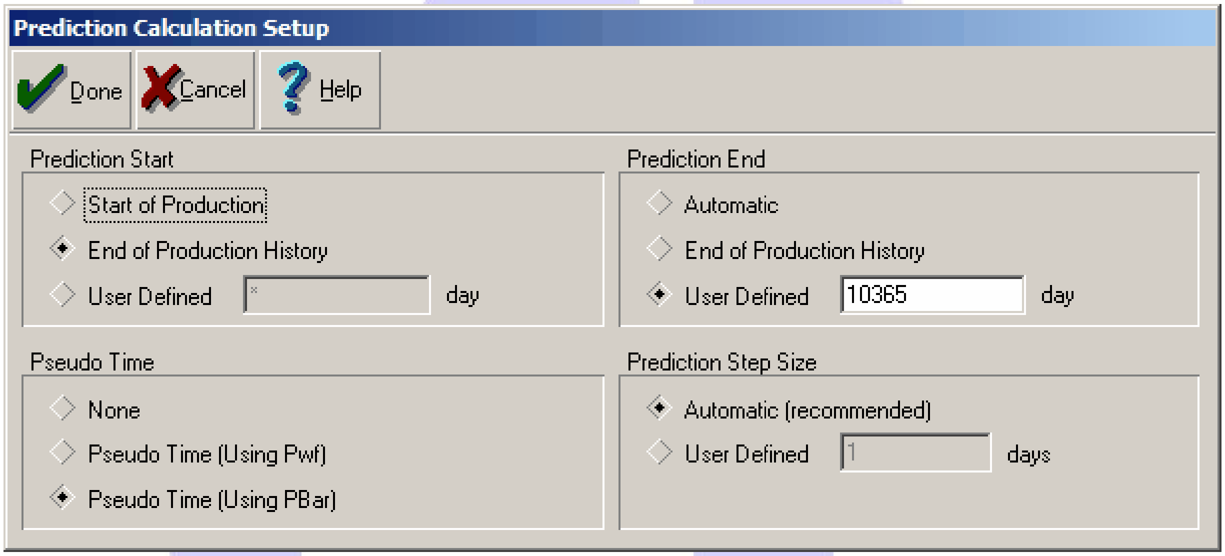
The match is now satisfactory so the production prediction can now be carried out.

3.4.4 Prediction

The prediction menu options are followed as before from top to bottom:


MBAL 9.0 - IPM 6.00 - Tight Gas Type Curves - tight gas example.mbi
File
Tool
Options
PVT
Input
History Matching
Production Prediction
View
Units
Help
Add Tank
Add Trans.
Add Well
Connect
Move
✓ Prediction Setup
✓ Production and Constraints
✓ Well Data
Run Prediction
Reports

In the prediction setup, options relating to the beginning and end of history can be defined, as well as selecting the pseudo time formulation:


Done
Cancel
Help

Prediction Calculation Setup

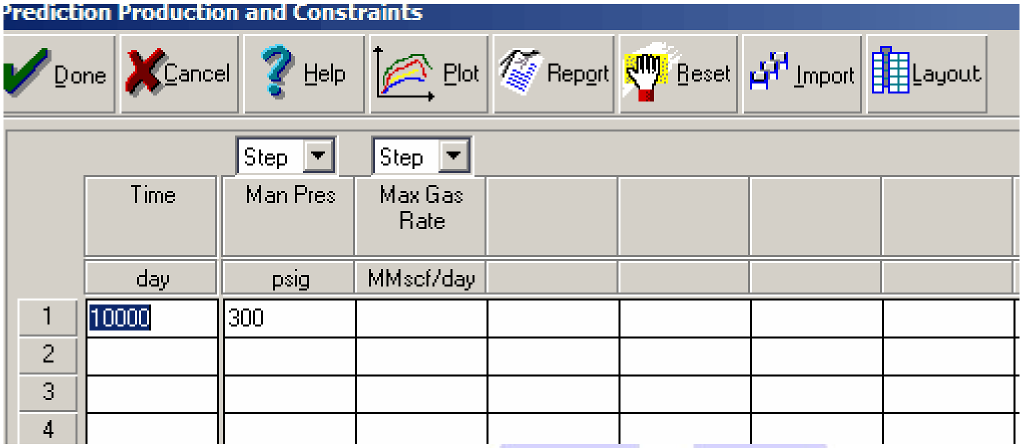
Prediction Start
- ○ Start of Production
- ● End of Production History
- ○ User Defined [*] day

Prediction End
- ○ Automatic
- ○ End of Production History
- ● User Defined [10365] day

Pseudo Time
- ○ None
- ○ Pseudo Time (Using Pwf)
- ● Pseudo Time (Using PBar)

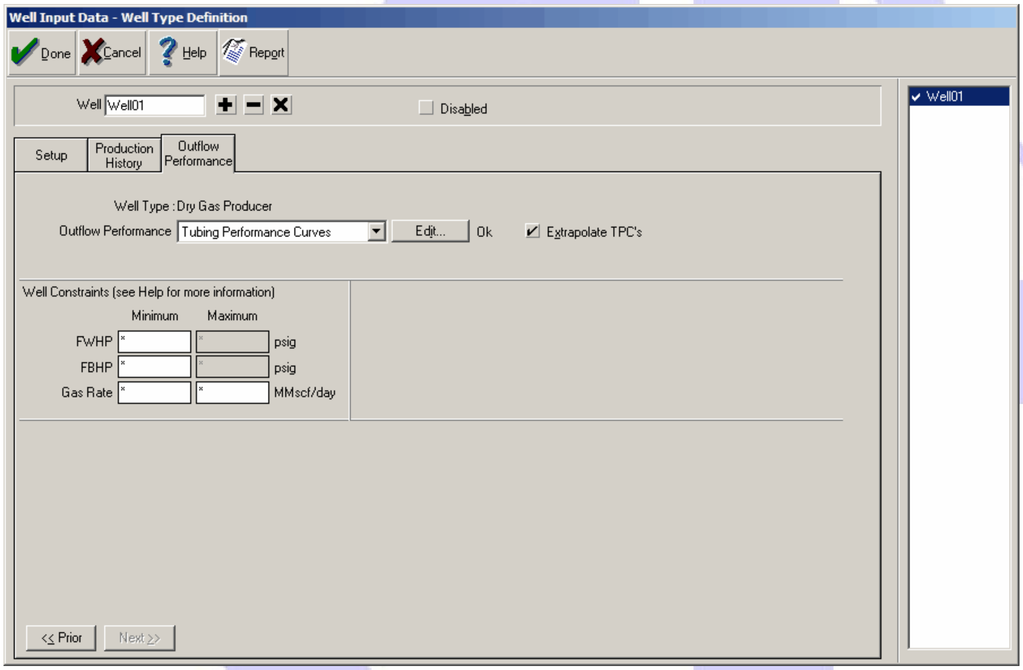
Prediction Step Size
- ● Automatic (recommended)
- ○ User Defined [1] days

In the next section (Production and Constraints), the well head pressure will need to be specified, along with any constraints that are to be imposed on the well:


Prediction Production and Constraints
Done
Cancel
Help
Plot
Report
Reset
Import
Layout

	Time	Step Man Pres	Step Max Gas Rate
	day	psig	MMscf/day
1	10000	300	
2			
3			
4			

The Well Data Section will now also require the VLP calculations, along with the Inputs and History of the well:


Well Input Data - Well Type Definition
Done
Cancel
Help
Report
Setup
Production History
Outflow Performance
Edit...
Ok
<< Prior
Next >>
✓ Well01

Well: Well01

☐ Disabled

Well Type : Dry Gas Producer

Outflow Performance: Tubing Performance Curves

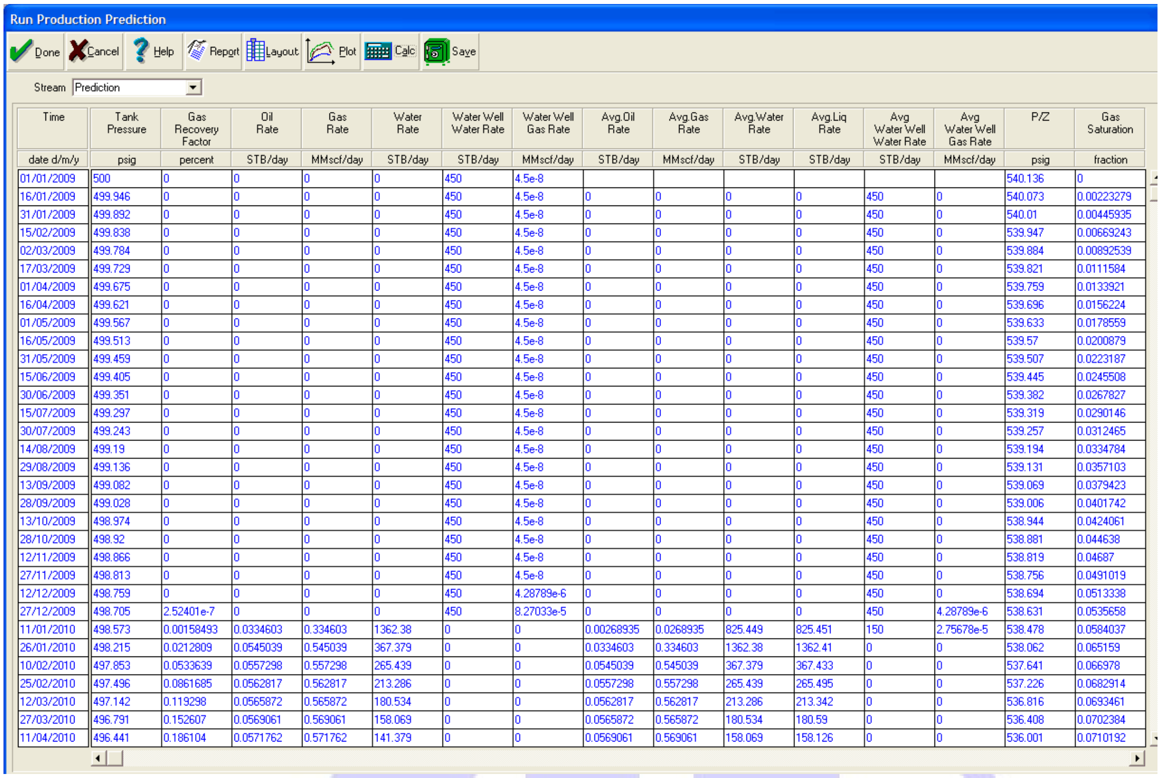
☑ Extrapolate TPC's

Well Constraints (see Help for more information)

	Minimum	Maximum	
FWHP	*	*	psig
FBHP	*	*	psig
Gas Rate	*	*	MMscf/day

The lift curve file to be uploaded is provided in the samples directory for this particular example, and is called tight "Tight Gas Well Model.tpd".

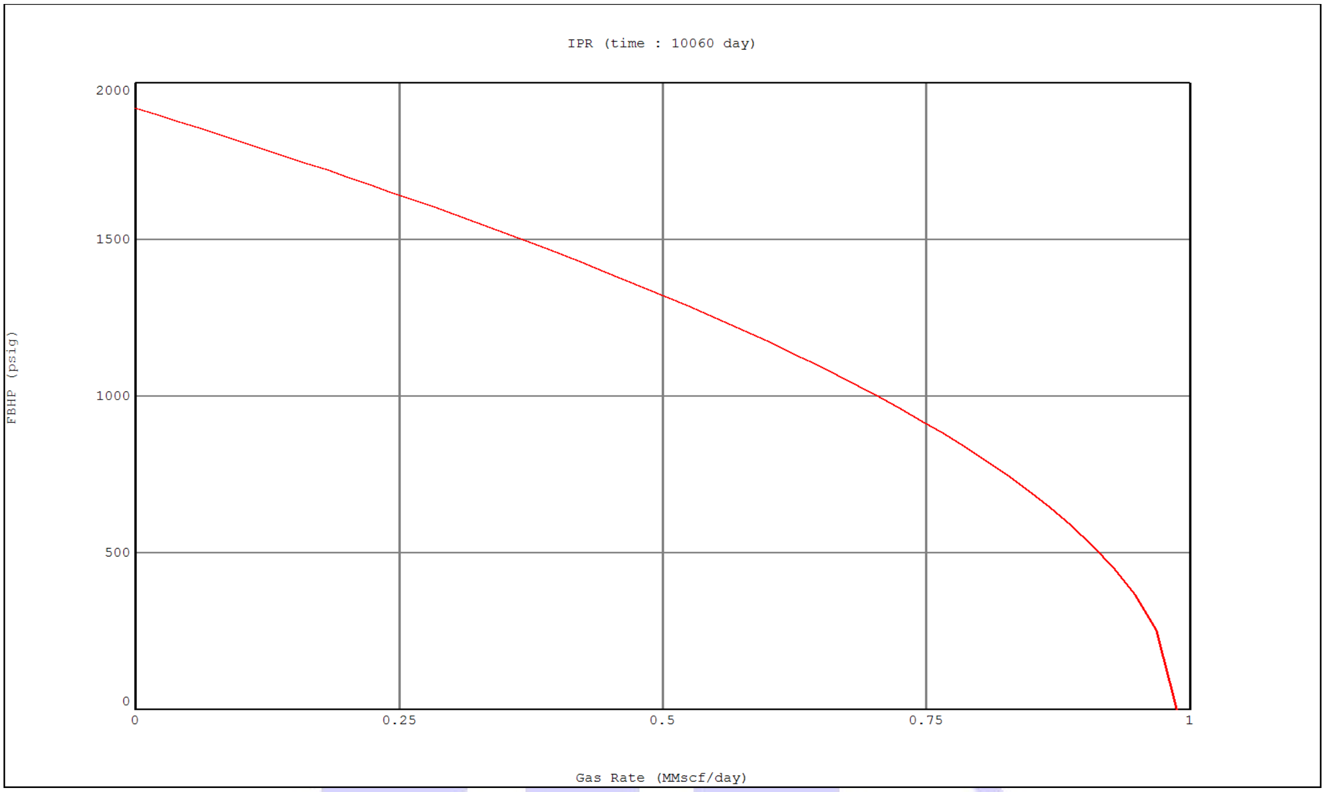
Having carried out all the steps above, the model is now ready to run in forecasting mode. The "Run Prediction" option can now be selected:



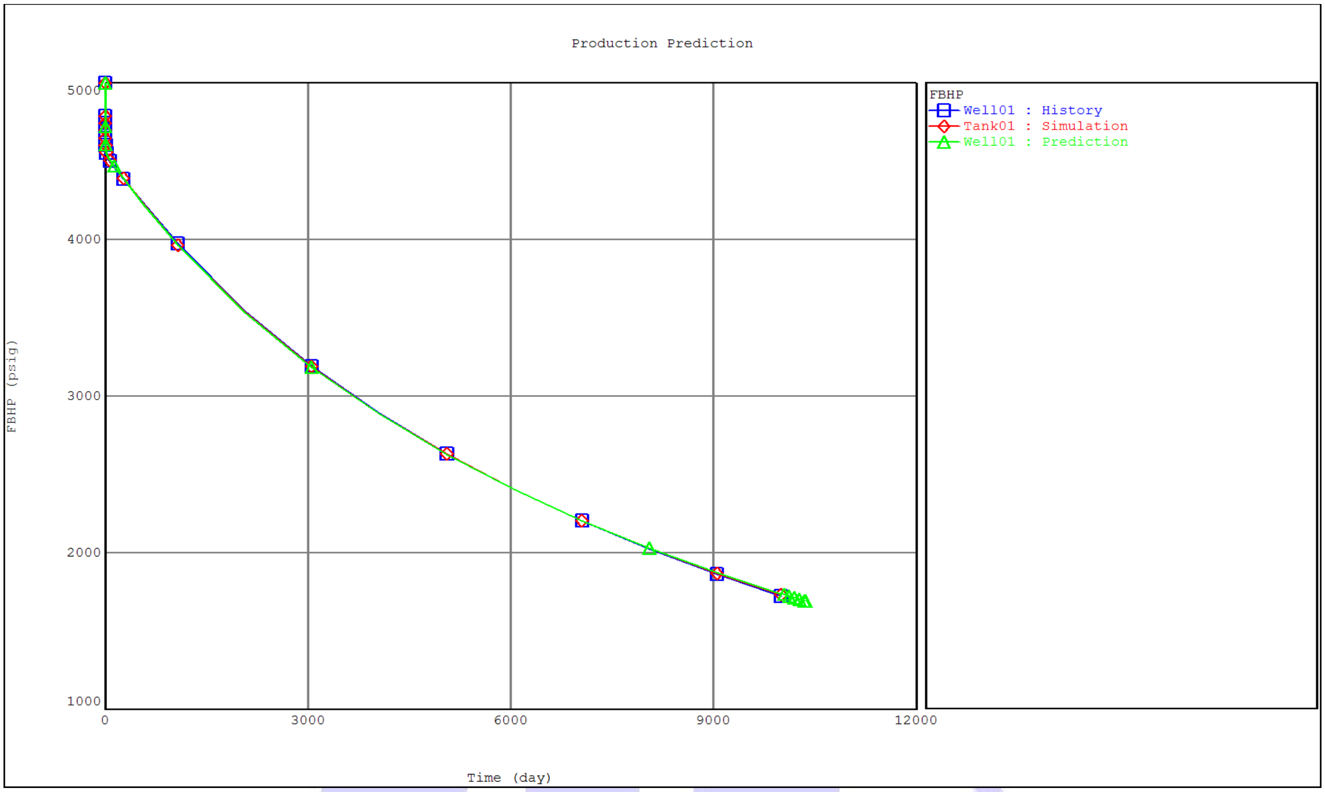
Stream Prediction

Time	Tank Pressure	Gas Recovery Factor	Oil Rate	Gas Rate	Water Rate	Water Well Water Rate	Water Well Gas Rate	Avg.Oil Rate	Avg.Gas Rate	Avg.Water Rate	Avg.Liq Rate	Avg Water Well Water Rate	Avg Water Well Gas Rate	P/Z	Gas Saturation
date d/m/y	psig	percent	STB/day	MMscf/day	STB/day	STB/day	MMscf/day	STB/day	MMscf/day	STB/day	STB/day	STB/day	MMscf/day	psig	fraction
01/01/2009	500	0	0	0	0	450	4.5e-8							540.136	0
16/01/2009	499.946	0	0	0	0	450	4.5e-8	0	0	0	0	450	0	540.073	0.00223279
31/01/2009	499.892	0	0	0	0	450	4.5e-8	0	0	0	0	450	0	540.01	0.00445935
15/02/2009	499.838	0	0	0	0	450	4.5e-8	0	0	0	0	450	0	539.947	0.00669243
02/03/2009	499.784	0	0	0	0	450	4.5e-8	0	0	0	0	450	0	539.884	0.00892539
17/03/2009	499.729	0	0	0	0	450	4.5e-8	0	0	0	0	450	0	539.821	0.0111584
01/04/2009	499.675	0	0	0	0	450	4.5e-8	0	0	0	0	450	0	539.759	0.0133921
16/04/2009	499.621	0	0	0	0	450	4.5e-8	0	0	0	0	450	0	539.696	0.0156224
01/05/2009	499.567	0	0	0	0	450	4.5e-8	0	0	0	0	450	0	539.633	0.0178559
16/05/2009	499.513	0	0	0	0	450	4.5e-8	0	0	0	0	450	0	539.57	0.0200879
31/05/2009	499.459	0	0	0	0	450	4.5e-8	0	0	0	0	450	0	539.507	0.0223187
15/06/2009	499.405	0	0	0	0	450	4.5e-8	0	0	0	0	450	0	539.445	0.0245508
30/06/2009	499.351	0	0	0	0	450	4.5e-8	0	0	0	0	450	0	539.382	0.0267827
15/07/2009	499.297	0	0	0	0	450	4.5e-8	0	0	0	0	450	0	539.319	0.0290146
30/07/2009	499.243	0	0	0	0	450	4.5e-8	0	0	0	0	450	0	539.257	0.0312465
14/08/2009	499.19	0	0	0	0	450	4.5e-8	0	0	0	0	450	0	539.194	0.0334784
29/08/2009	499.136	0	0	0	0	450	4.5e-8	0	0	0	0	450	0	539.131	0.0357103
13/09/2009	499.082	0	0	0	0	450	4.5e-8	0	0	0	0	450	0	539.069	0.0379423
28/09/2009	499.028	0	0	0	0	450	4.5e-8	0	0	0	0	450	0	539.006	0.0401742
13/10/2009	498.974	0	0	0	0	450	4.5e-8	0	0	0	0	450	0	538.944	0.0424061
28/10/2009	498.92	0	0	0	0	450	4.5e-8	0	0	0	0	450	0	538.881	0.044638
12/11/2009	498.866	0	0	0	0	450	4.5e-8	0	0	0	0	450	0	538.819	0.04687
27/11/2009	498.813	0	0	0	0	450	4.5e-8	0	0	0	0	450	0	538.756	0.0491019
12/12/2009	498.759	0	0	0	0	450	4.28789e-6	0	0	0	0	450	0	538.694	0.0513338
27/12/2009	498.705	2.52401e-7	0	0	0	450	8.27033e-5	0	0	0	0	450	4.28789e-6	538.631	0.0535658
11/01/2010	498.573	0.00158493	0.0334603	0.334603	1362.38	0	0	0.00268935	0.0268935	825.449	825.451	150	2.75678e-5	538.478	0.0584037
26/01/2010	498.215	0.0212809	0.0545039	0.545039	367.379	0	0	0.0334603	0.334603	1362.38	1362.41	0	0	538.062	0.065159
10/02/2010	497.853	0.0533639	0.0557298	0.557298	265.439	0	0	0.0545039	0.545039	367.379	367.433	0	0	537.641	0.066978
25/02/2010	497.496	0.0861685	0.0562817	0.562817	213.286	0	0	0.0557298	0.557298	265.439	265.495	0	0	537.226	0.0682914
12/03/2010	497.142	0.119298	0.0565872	0.565872	180.534	0	0	0.0562817	0.562817	213.286	213.342	0	0	536.816	0.0693461
27/03/2010	496.791	0.152607	0.0569061	0.569061	158.069	0	0	0.0565872	0.565872	180.534	180.59	0	0	536.408	0.0702384
11/04/2010	496.441	0.186104	0.0571762	0.571762	141.379	0	0	0.0569061	0.569061	158.069	158.126	0	0	536.001	0.0710192

If well results are selected, the analysis buttons become active, allowing fully transient IPRs over the prediction period to be viewed:



The plots will now show the forecasted behaviour of the well, along with the history and simulation if needed:



This step marks the end of the Tight Gas example.

3.5 Other Example Files

This section describes the other example MBI files that are installed with **MBAL.** The user is invited to explore these examples and use them as starting points for building field models.

CALCWELL.MBI
Used by the CALCWELL.XLS open server example.

DETAILED2.MBI
Used by the DA2.XLS open server example.

FRACT FLOW MATCH1.MBI
Used by the FRACT_FLOW_MATCH1.XLS open server example.

FRACT FLOW MATCH2.MBI
Used by the FRACT_FLOW_MATCH2.XLS open server example.

GAS.MBI
Example of a single tank gas example.

MULTIOIL.MBI
Example of a multi-tank oil example.

MULTIPVT.MBI
Example of a variable PVT example.

OIL.MBI
Example of a single tank oil example.

SIMPLE2.MBI
Used by the DA1.XLS open server example.

STEP1.MBI
Used by the STEP1.XLS open server example.

STEP2.MBI
Used by the STEP2.XLS open server example.

STEP3.MBI
Used by the STEP3.XLS open server example.

3.6 Streamlines Example

The 2D streamlines calculation is intended to evaluate the effects of well positioning within the reservoir, and the impact on (i) water breakthrough and (ii) water cut evolution.

Background to Streamlines tool

Material balance models can be used to perform history matching, for which it is a formidable tool (using the concept of expansion energy). This same strength however, does not requires the specification of geometry and therefore cannot predict WC evolution (unless extrapolated from history using pseudo Rel. Perms).

For this reason the 2D streamlines calculation was introduced (in IPM8.0) which can track the evolution of the water front. Streamlines can be used to approximate the relative evolution of a fluid, thus resulting in breakthrough times and water cut evolution results.

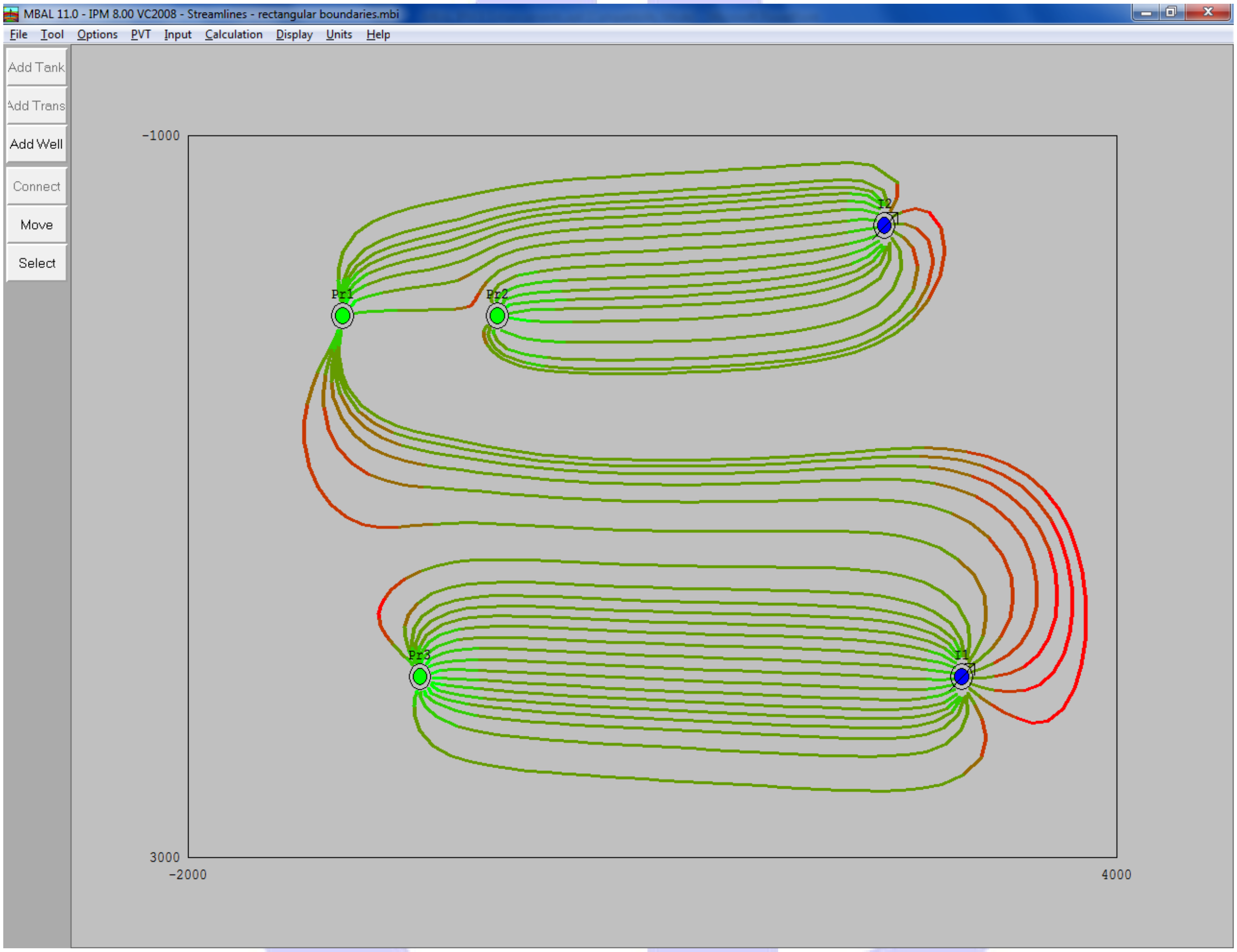
3.6.1 Calculation Methodology

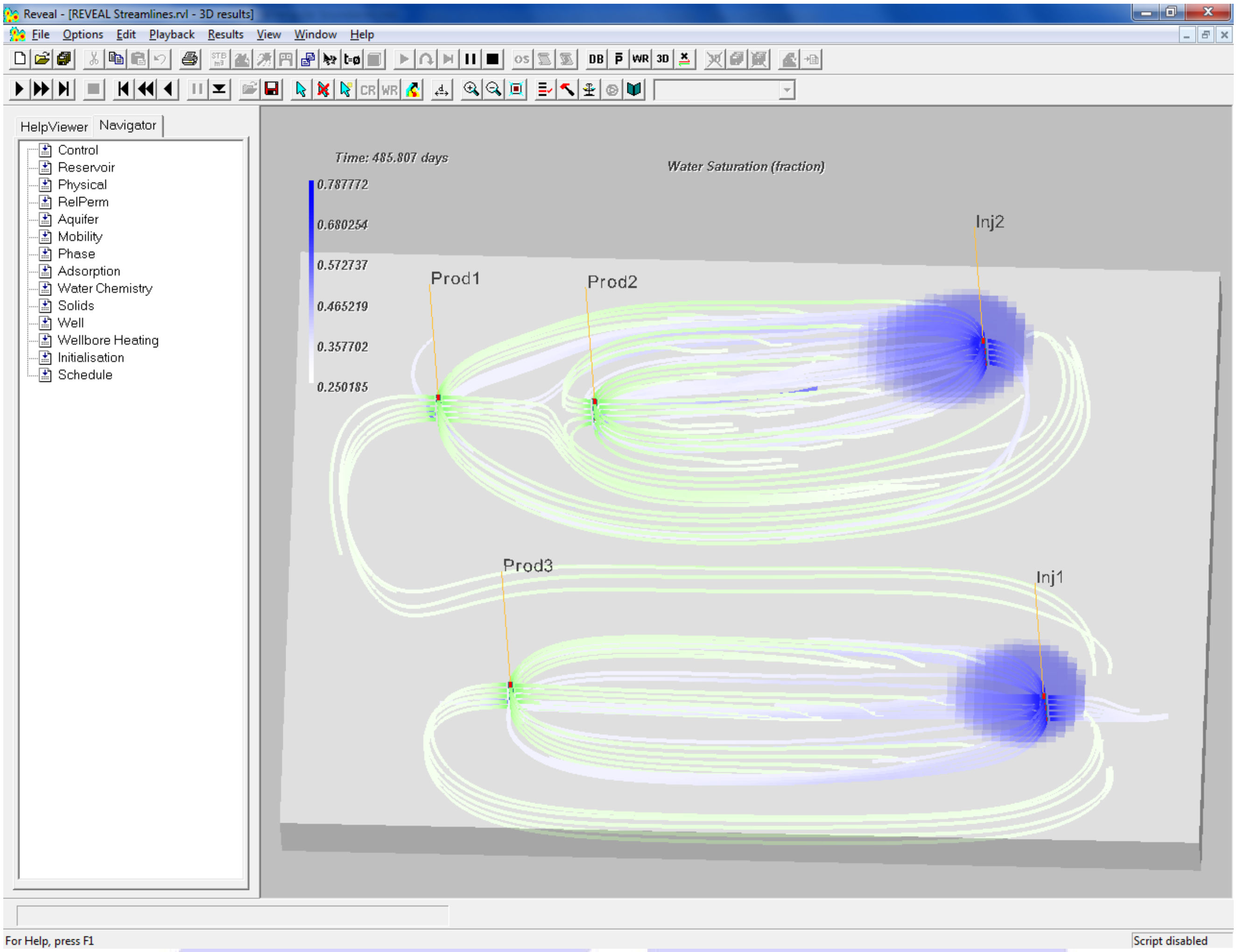
Streamlines Calculation Methodology

- Image wells are generated to model the reservoir boundaries.

- The velocity field is calculated so that the time simulation can be performed.
    - Once a streamline reaches a producer the production water cut increases. Of course if more streamlines reach the producer than the evolution of water cut (and indeed breakthrough) would occur much faster.
- The calculation tracks the progression of water along the stream tubes with time.

The screen shot below shows the comparison of the streamlines calculation in MBAL a like for like simulation in REVEAL.


MBAL 11.0 - IPM 8.00 VC2008 - Streamlines - rectangular boundaries.mbi
File
Tool
Options
PVT
Input
Calculation
Display
Units
Help
Add Tank
Add Trans
Add Well
Connect
Move
Select
-1000
3000
-2000
4000
Pr1
Pr2
Pr3
I2
I1


Reveal - [REVEAL Streamlines.rvl - 3D results]
File Options Edit Playback Results View Window Help
HelpViewer Navigator
Control
Reservoir
Physical
RelPerm
Aquifer
Mobility
Phase
Adsorption
Water Chemistry
Solids
Well
Wellbore Heating
Initialisation
Schedule
Time: 485.807 days
Water Saturation (fraction)
0.787772
0.680254
0.572737
0.465219
0.357702
0.250185
Prod1
Prod2
Inj2
Prod3
Inj1
For Help, press F1
Script disabled

Outputs from the streamlines Calculation

The following information can be gained by performing a Streamlines calculation:

- Breakthrough times
- This calculation allows the user to infer which injector is supporting which producer in the reservoir, and by how much (%)
- Finally, the streamlines can be used to screen the sweep efficiency of well configuration.

3.6.2 Objectives

Exercise Objectives & Learning summary

In this example we are considering a reservoir that contains three (3) producing wells and the intention is to support production with use of two (2) water injection wells.

However, before analysing the practical implications (drilling schedule, location of wells, depths, etc…) it is required to perform a quick screening calculation to estimate the viability of the proposed scheme. The streamlines calculation will be used to do this.

There are two objectives to achieve in this step by step worked example:

1. Calculate the breakthrough times for producer wells
2. Ascertain which producer is being supported by which injection well.

3.6.3 Available Data

Available Data

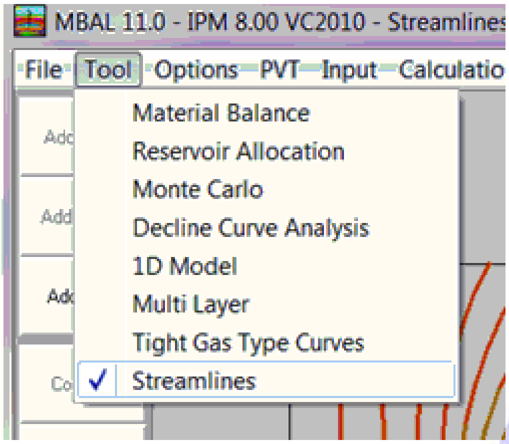
The following data is available and will be detailed in the step by step example:

- PVT
- Streamlines Calculation Input
    - 2D Reservoir Geometry
    - Reservoir Properties
    - 2D Well locations
    - Calculation Times

3.6.4 Step By Step Guide

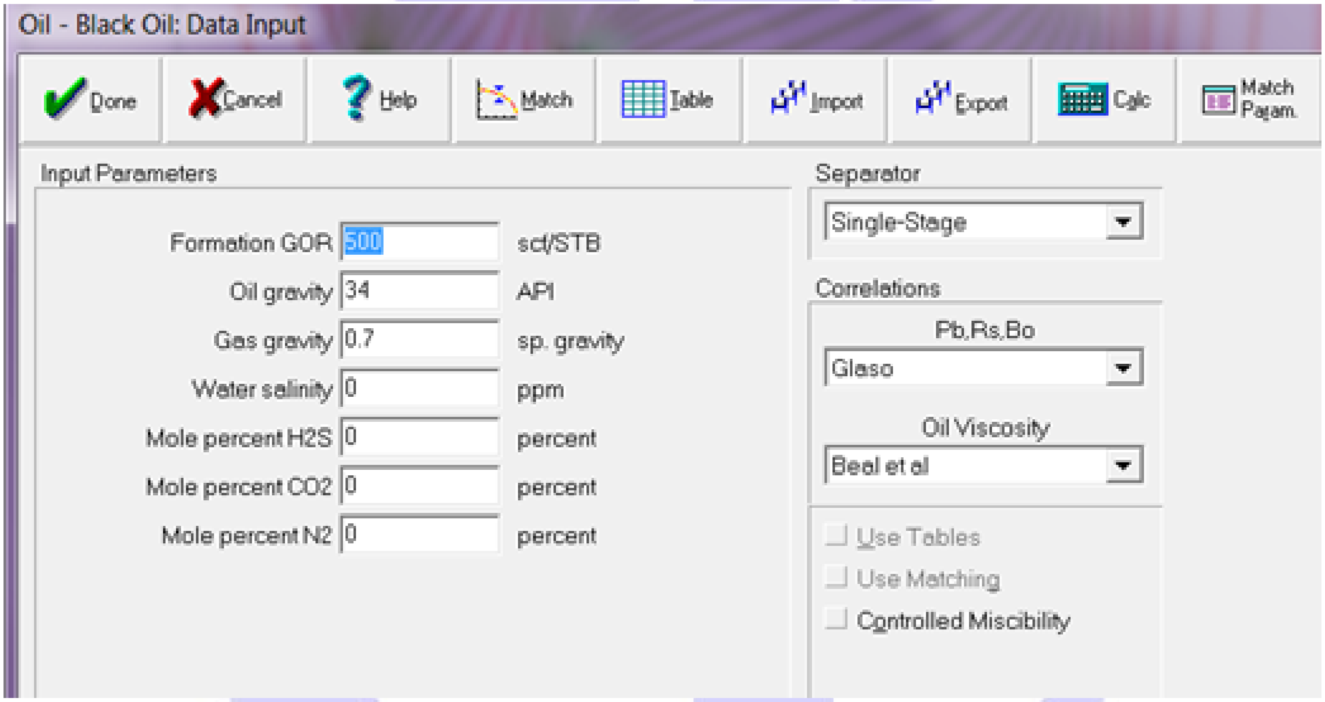
Step By Step Guide

Open MBAL and under tools select the streamlines Calculation.


MBAL 11.0 - IPM 8.00 VC2010 - Streamlines
File
Tool
Options
PVT
Input
Calculatio
Material Balance
Reservoir Allocation
Monte Carlo
Decline Curve Analysis
1D Model
Multi Layer
Tight Gas Type Curves
✓ Streamlines

3.6.4.1 PVT

Press ***PVT|Fluid properties*** and enter the following PVT parameters that describes the reservoir fluid:


Oil - Black Oil: Data Input
Done
Cancel
Help
Match
Table
Import
Export
Calc
Match Param.

Input Parameters

Formation GOR	500	scf/STB
Oil gravity	34	API
Gas gravity	0.7	sp. gravity
Water salinity	0	ppm
Mole percent H2S	0	percent
Mole percent CO2	0	percent
Mole percent N2	0	percent

Separator: Single-Stage

Correlations
Pb,Rs,Bo: Glaso
Oil Viscosity: Beal et al

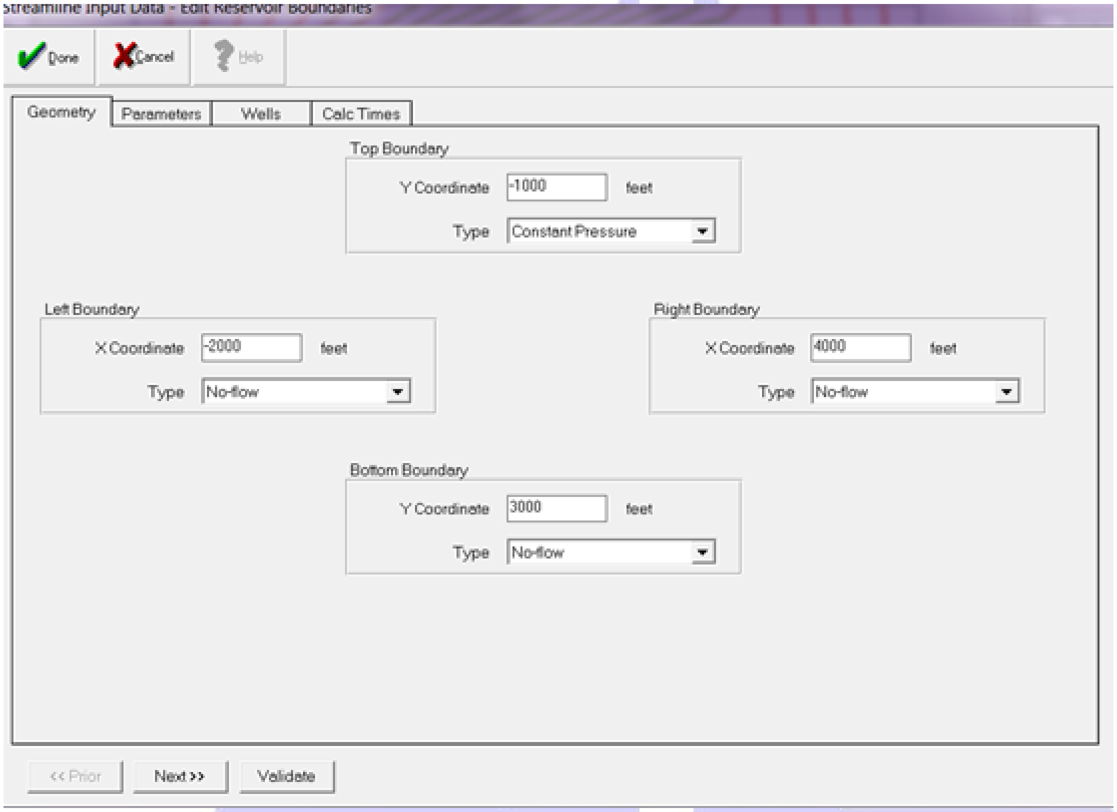
☐ Use Tables
☐ Use Matching
☐ Controlled Miscibility

Having entered this data, press done.

3.6.4.2 Calculation Input

Pressing ***Input| Input Data*** allows the input to the streamlines calculation to be specified: enter the data as per the below screen shots:

Reservoir Geometry: The reservoir is to be described using simple Cartesian co-ordinate systems (i.e. x, y). Please note that the top boundary is defined as a constant pressure boundary.


Streamline Input Data - Edit Reservoir Boundaries
Done
Cancel
Help
Geometry
Parameters
Wells
Calc Times
<< Prior
Next >>
Validate

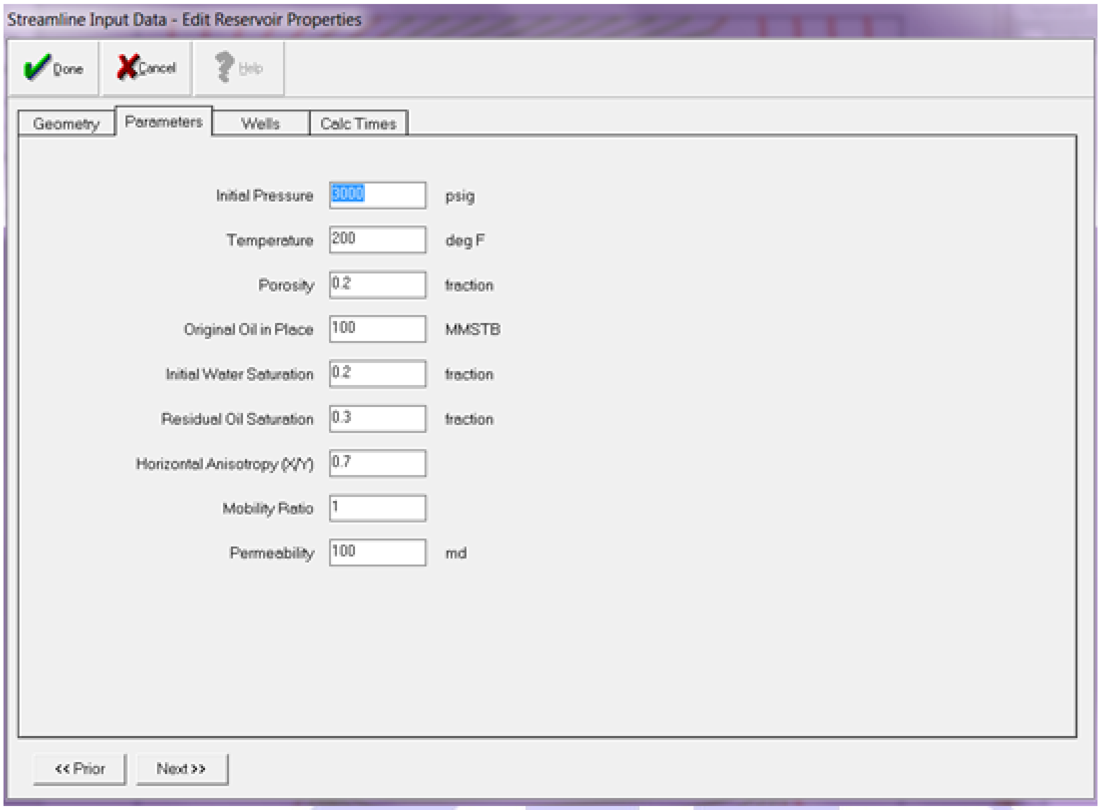
Top Boundary
Y Coordinate: -1000 feet
Type: Constant Pressure

Left Boundary
X Coordinate: -2000 feet
Type: No-flow

Right Boundary
X Coordinate: 4000 feet
Type: No-flow

Bottom Boundary
Y Coordinate: 3000 feet
Type: No-flow

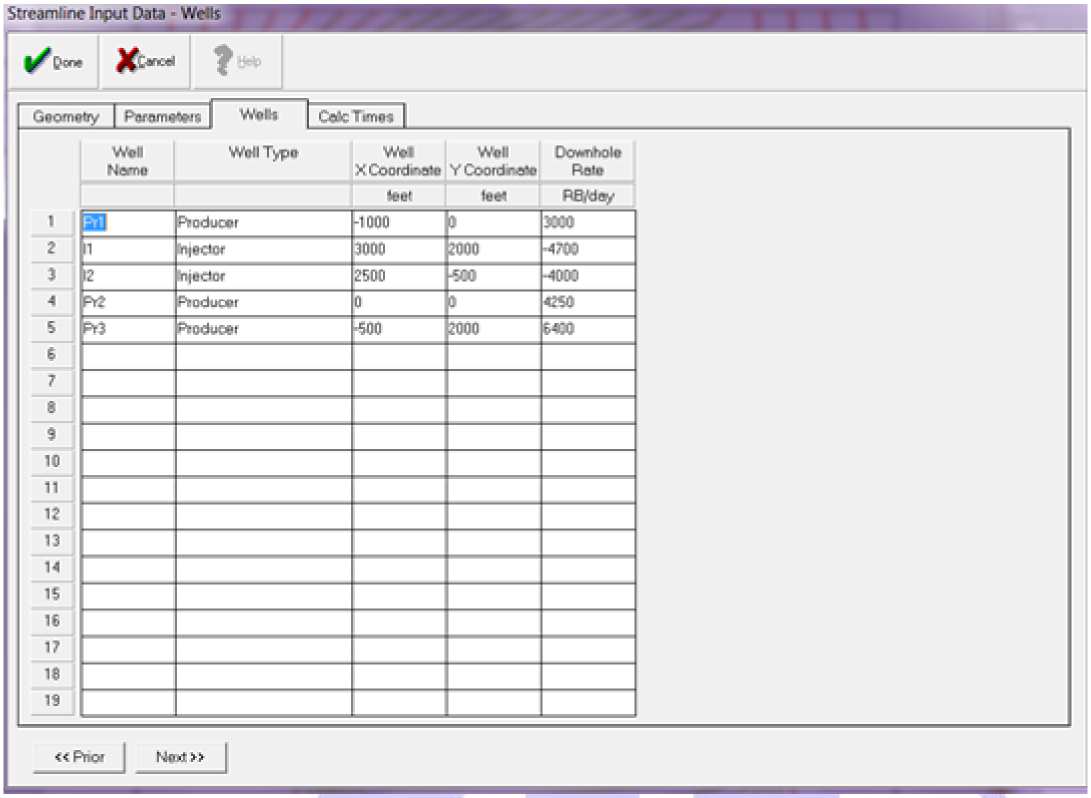
Reservoir Parameters: In this section the reservoir properties are defined.


Streamline Input Data - Edit Reservoir Properties
Done
Cancel
Help
Geometry
Parameters
Wells
Calc Times
<< Prior
Next >>

Initial Pressure 3000 psig
Temperature 200 deg F
Porosity 0.2 fraction
Original Oil in Place 100 MMSTB
Initial Water Saturation 0.2 fraction
Residual Oil Saturation 0.3 fraction
Horizontal Anisotropy (X/Y) 0.7
Mobility Ratio 1
Permeability 100 md

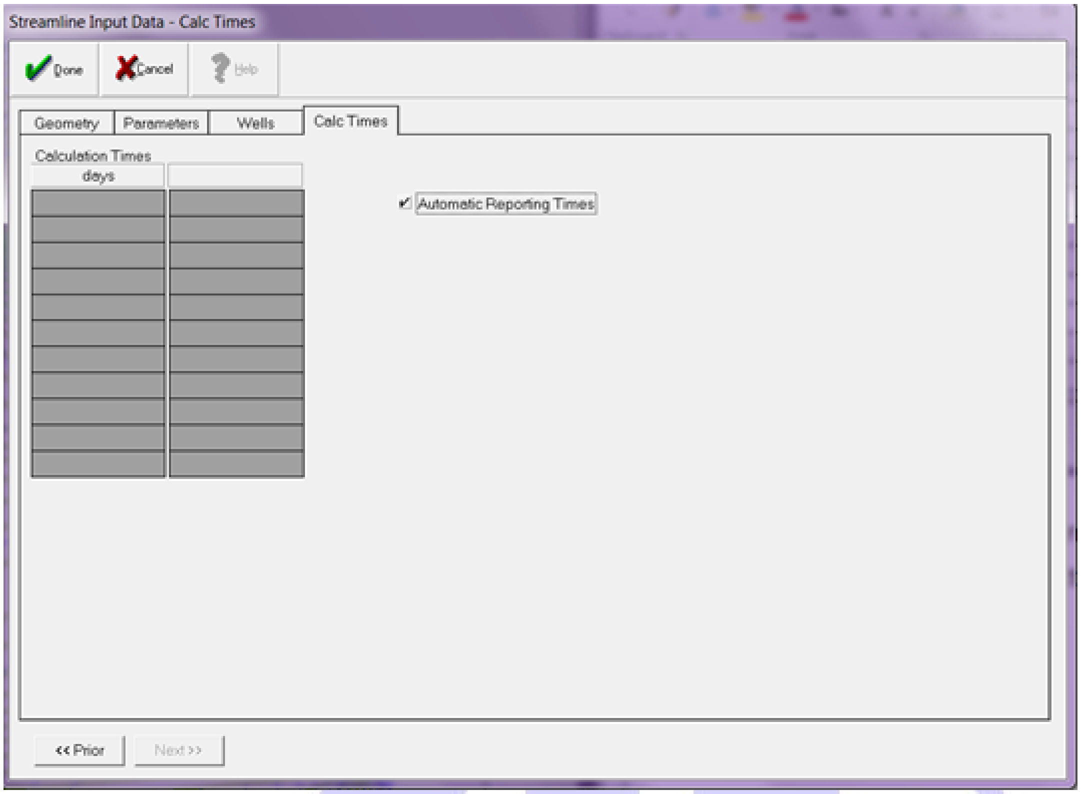
Wells: In this section the wells are described in two ways, (i) their location in the defined Reservoir Geometry is required, and (ii) the type of well (i.e. producer or injector) including the production/injection rate.

Note: Please note the sign convention adopted by the downhole injection rate (i.e. negative)


Streamline Input Data - Wells
Done
Cancel
Help
Geometry
Parameters
Wells
Calc Times
<< Prior
Next >>

	Well Name	Well Type	Well X Coordinate	Well Y Coordinate	Downhole Rate
			feet	feet	RB/day
1	Pr1	Producer	-1000	0	3000
2	I1	Injector	3000	2000	-4700
3	I2	Injector	2500	-500	-4000
4	Pr2	Producer	0	0	4250
5	Pr3	Producer	-500	2000	6400
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					

Calculation Times: In this screen the calculation times may be left blank, however the automatic reporting times should be selected.

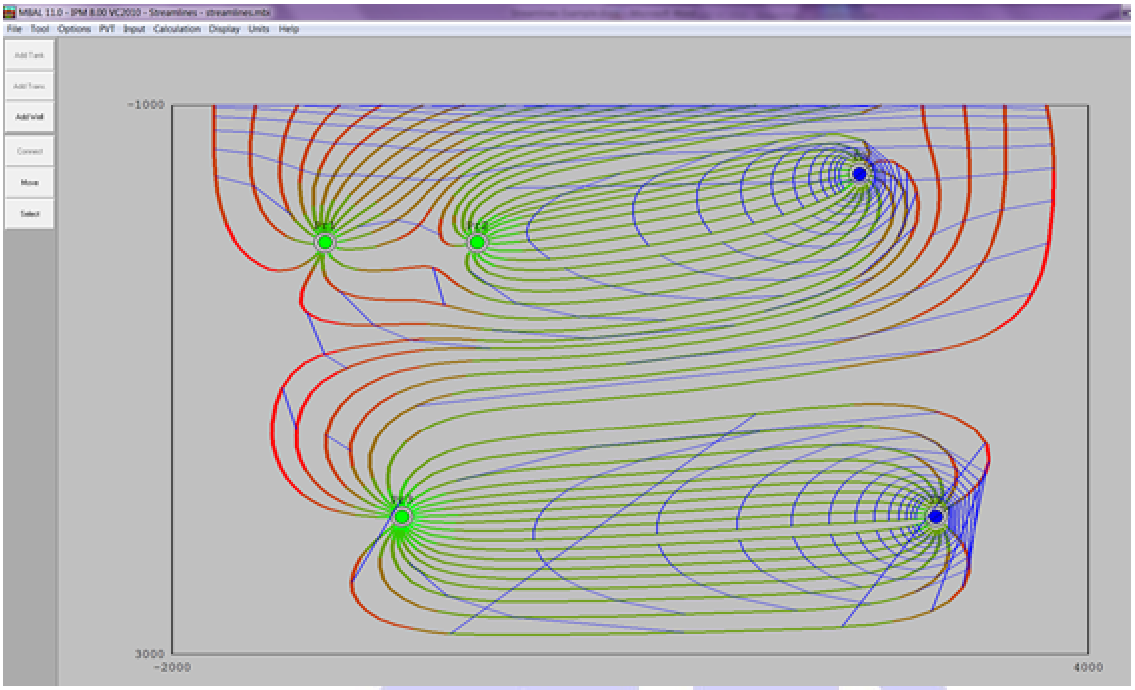

Streamline Input Data - Calc Times
Done
Cancel
Help
Geometry
Parameters
Wells
Calc Times
Calculation Times
days
<< Prior
Next >>

☑ Automatic Reporting Times

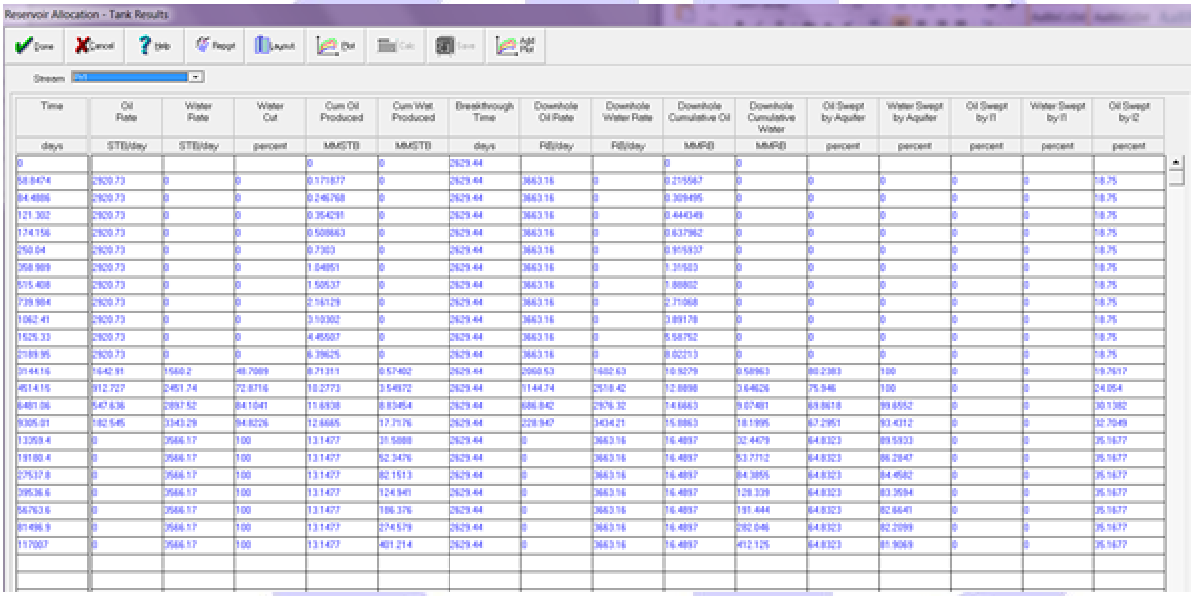
3.6.4.3 Results

Generating Results

Pressing ***Calculation| Calculate*** performs the streamlines calculation


MBAL 11.0 - IPM 8.00 VC2010 - Streamlines - streamlines.mbi
File Tool Options PVT Input Calculation Display Units Help
Add Tank
Add Trans
Add Well
Connect
Move
Select
-1000
3000
-2000
4000

To see the results in tabular form press ***Calculation |Calculation Results***, using the drop down menu select Producer 1 (the default is to show the reservoir results).


Reservoir Allocation - Tank Results
Done
Cancel
Help
Report
Layout
Plot
Calc
Save
Add Plot
Stream

Time	Oil Rate	Water Rate	Water Cut	Cum Oil Produced	Cum Wat Produced	Breakthrough Time	Downhole Oil Rate	Downhole Water Rate	Downhole Cumulative Oil	Downhole Cumulative Water	Oil Swept by Aquifer	Water Swept by Aquifer	Oil Swept by I1	Water Swept by I1	Oil Swept by I2
days	STB/day	STB/day	percent	MMSTB	MMSTB	days	RB/day	RB/day	MMRB	MMRB	percent	percent	percent	percent	percent
0				0	0	2629.44			0	0					
58.8474	2920.73	0	0	0.171877	0	2629.44	3663.16	0	0.215567	0	0	0	0	0	18.75
84.4886	2920.73	0	0	0.246768	0	2629.44	3663.16	0	0.309495	0	0	0	0	0	18.75
121.302	2920.73	0	0	0.354291	0	2629.44	3663.16	0	0.444349	0	0	0	0	0	18.75
174.156	2920.73	0	0	0.508663	0	2629.44	3663.16	0	0.637962	0	0	0	0	0	18.75
250.04	2920.73	0	0	0.7303	0	2629.44	3663.16	0	0.915937	0	0	0	0	0	18.75
358.989	2920.73	0	0	1.04851	0	2629.44	3663.16	0	1.31503	0	0	0	0	0	18.75
515.408	2920.73	0	0	1.50537	0	2629.44	3663.16	0	1.88802	0	0	0	0	0	18.75
739.984	2920.73	0	0	2.16129	0	2629.44	3663.16	0	2.71068	0	0	0	0	0	18.75
1062.41	2920.73	0	0	3.10302	0	2629.44	3663.16	0	3.89178	0	0	0	0	0	18.75
1525.33	2920.73	0	0	4.45507	0	2629.44	3663.16	0	5.58752	0	0	0	0	0	18.75
2189.95	2920.73	0	0	6.39625	0	2629.44	3663.16	0	8.02213	0	0	0	0	0	18.75
3144.16	1642.91	1560.2	48.7089	8.71311	0.57402	2629.44	2060.53	1602.63	10.9279	0.58963	80.2383	100	0	0	19.7617
4514.15	912.727	2451.74	72.8716	10.2773	3.54972	2629.44	1144.74	2518.42	12.8898	3.64626	75.946	100	0	0	24.054
6481.06	547.636	2897.52	84.1041	11.6938	8.83454	2629.44	686.842	2976.32	14.6663	9.07481	69.8618	99.6552	0	0	30.1382
9305.01	182.545	3343.29	94.8226	12.6665	17.7176	2629.44	228.947	3434.21	15.8863	18.1995	67.2951	93.4312	0	0	32.7049
13359.4	0	3566.17	100	13.1477	31.5888	2629.44	0	3663.16	16.4897	32.4479	64.8323	89.5933	0	0	35.1677
19180.4	0	3566.17	100	13.1477	52.3476	2629.44	0	3663.16	16.4897	53.7712	64.8323	86.2947	0	0	35.1677
27537.8	0	3566.17	100	13.1477	82.1513	2629.44	0	3663.16	16.4897	84.3855	64.8323	84.4582	0	0	35.1677
39536.6	0	3566.17	100	13.1477	124.941	2629.44	0	3663.16	16.4897	128.339	64.8323	83.3584	0	0	35.1677
56763.6	0	3566.17	100	13.1477	186.376	2629.44	0	3663.16	16.4897	191.444	64.8323	82.6641	0	0	35.1677
81496.9	0	3566.17	100	13.1477	274.579	2629.44	0	3663.16	16.4897	282.046	64.8323	82.2099	0	0	35.1677
117007	0	3566.17	100	13.1477	401.214	2629.44	0	3663.16	16.4897	412.125	64.8323	81.9069	0	0	35.1677

3.6.4.4 Conclusion

Conclusions

Taking Producer 1 for illustrative purposes:

- Breakthrough time is estimated to be 2629.44 days
- It appears that producer 1 is supported by injector 2 (again this can also be inferred from the streamlines in the above diagram).

These are the results for the current injector/producer configuration, and thus the expected sweep efficiency is calculated. Of course one could then alter the configuration and re-run the calculation.

3.7 1D EOR Example

Introduction

The 1D model allows study of oil displacement by water/gas using the fractional flow and Buckley-Leverett equations. ***In IPM8.0*** this model was modified to account for various enhanced oil recovery (EOR) operations that are now commonplace in the industry.

This model should be used to perform quick comparisons of different flood methods and assess the resulting difference of sweep efficiency. It must be stressed that this is intended as a scoping tool, rather than a rigorous physical and mathematical description of the reservoir (i.e. a numerical simulator like REVEAL).

The 1D simulation model in MBAL can be used to comprehend some basic physics of various techniques, before attempting the full 3D simulation effort.

The modifications to the 1D Model allow the following EOR methods to be approximated:

- Polymer injection
- Surfactant
- Temperature effects within the reservoir ()Hot water)
- CO_2 injection.

3.7.1 Objectives

Exercise Objectives and Learning Summary

The reservoir in question is well into decline and the decision has been made to support production.

The objective of this exercise is to screen which EOR technique to employ for this reservoir, either (i) hot water injection, (ii) Polymer injection, (iii) Surfactant injection, or indeed some combination of (ii) and (iii).

The technique that gives the highest recovery factor will then be the subject of more detailed numerical simulation work.

3.7.2 Approach

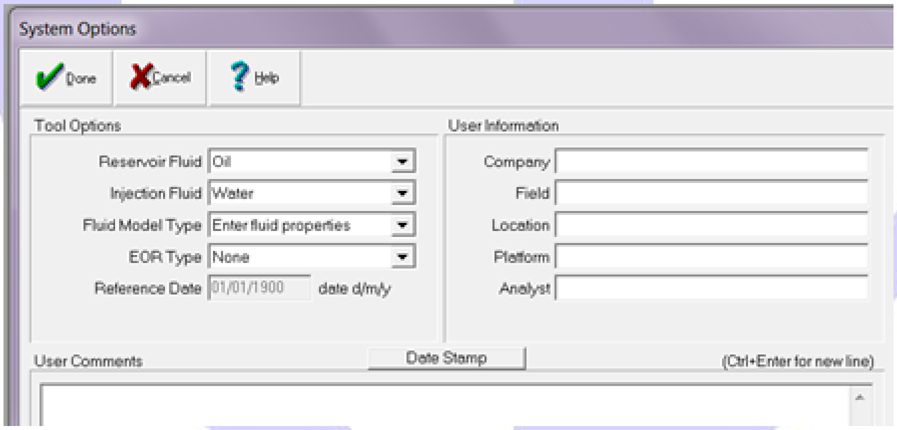
Approach

The approach would initially be to setup the base case, and then use the 1D EOR model to assess the different techniques of EOR.

The remainder of this exercise will present a step by step approach to performing this analysis:

3.7.3 Base Case

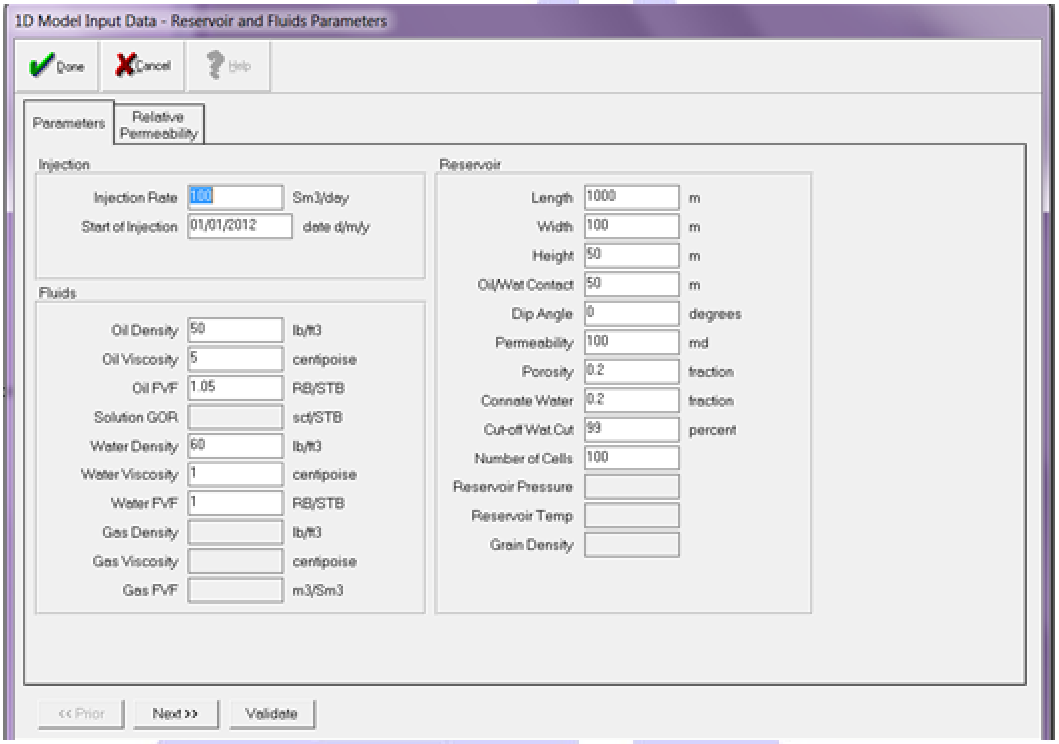
- Starting from an entirely new MBAL file, press ***Tools*** and select the ***1D model***
- Pressing Options allows the user to specify the system that is to be modelled.
    - Reservoir fluid is ***Oil***, injection fluid is ***water*** and the fluid is to be modelled using the ***entered fluid properties***.
    - ***No EOR*** technique is specified since this is the base case.


System Options
Done
Cancel
Help
Tool Options
User Information
Company
Field
Location
Platform
Analyst
User Comments
Date Stamp
(Ctrl+Enter for new line)

Reservoir Fluid: Oil
Injection Fluid: Water
Fluid Model Type: Enter fluid properties
EOR Type: None
Reference Date: 01/01/1900 date d/m/y

3.7.3.1 Base case Parameters

- Pressing ***Input| Reservoir Parameters*** allows the user to enter reservoir properties alongside the fluid properties.



1D Model Input Data - Reservoir and Fluids Parameters

Injection

Injection Rate	100	Sm3/day
Start of Injection	01/01/2012	date d/m/y

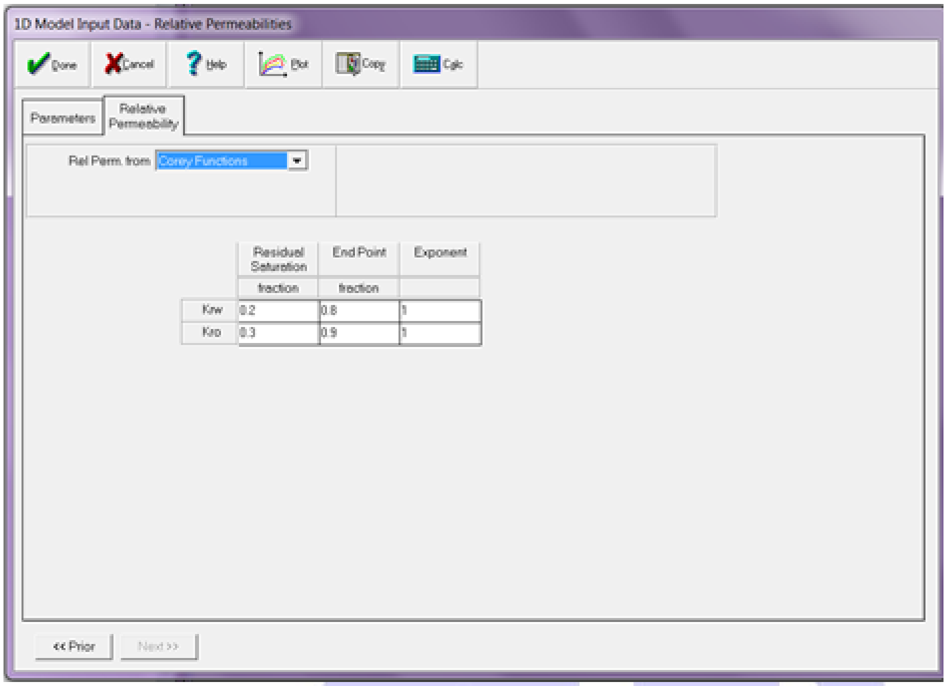
Fluids

Oil Density	50	lb/ft3
Oil Viscosity	5	centipoise
Oil FVF	1.05	RB/STB
Solution GOR		scf/STB
Water Density	60	lb/ft3
Water Viscosity	1	centipoise
Water FVF	1	RB/STB
Gas Density		lb/ft3
Gas Viscosity		centipoise
Gas FVF		m3/Sm3

Reservoir

Length	1000	m
Width	100	m
Height	50	m
Oil/Wat Contact	50	m
Dip Angle	0	degrees
Permeability	100	md
Porosity	0.2	fraction
Connate Water	0.2	fraction
Cut-off Wat Cut	99	percent
Number of Cells	100	
Reservoir Pressure		
Reservoir Temp		
Grain Density		

- The Relative Permeability data is also required


Done
Cancel
Help
Plot
Copy
Calc
Parameters
Relative Permeability
<< Prior
Next >>

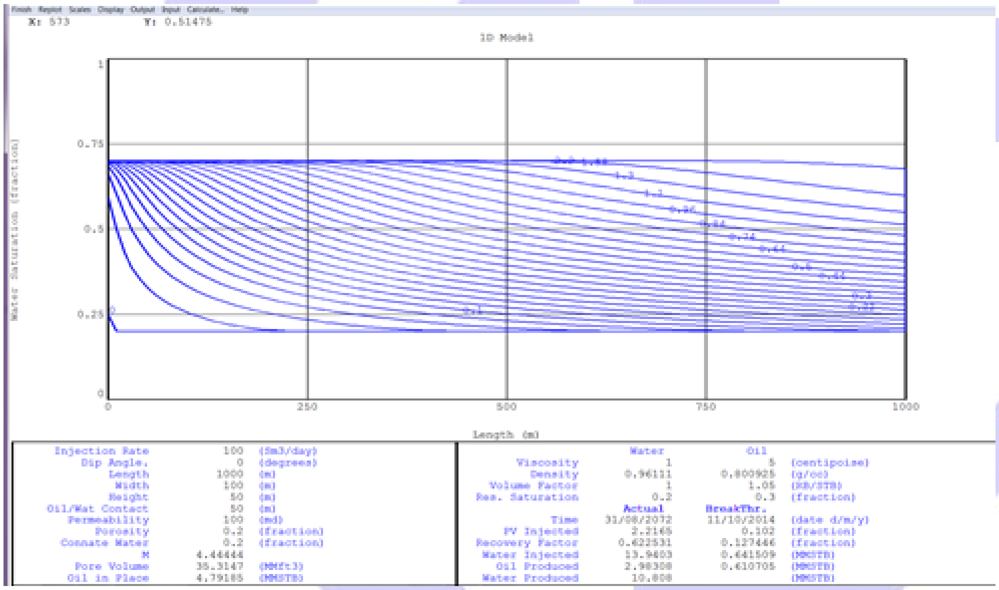
1D Model Input Data - Relative Permeabilities

Rel Perm. from: Corey Functions

	Residual Saturation	End Point	Exponent
	fraction	fraction	
Krw	0.2	0.8	1
Kro	0.3	0.9	1

3.7.3.2 Base Case Results

- Press Calculate| Run Simulation, within the plot menu press calculate to perform the simulation.

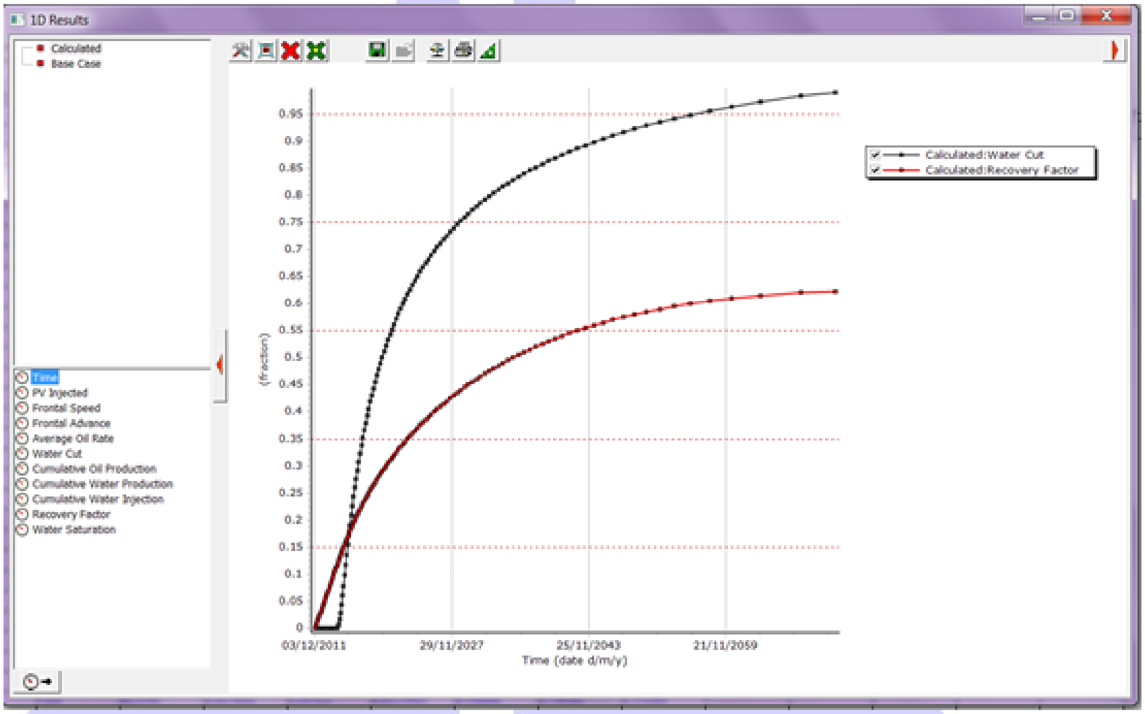

Finish
Replot
Scales
Display
Output
Input
Calculate..
Help
X: 573
Y: 0.51475
1D Model
Water Saturation (fraction)
1
0.75
0.5
0.25
0
0
250
500
750
1000
Length (m)

```
  Injection Rate        100  (Sm3/day)
      Dip Angle.          0  (degrees)
          Length       1000  (m)
           Width        100  (m)
          Height         50  (m)
 Oil/Wat Contact         50  (m)
    Permeability        100  (md)
        Porosity        0.2  (fraction)
   Connate Water        0.2  (fraction)
               M    4.44444
     Pore Volume    35.3147  (MMft3)
    Oil in Place    4.79185  (MMSTB)
```

```
                         Water           Oil
         Viscosity           1             5  (centipoise)
           Density     0.96111      0.800925  (g/cc)
     Volume Factor           1          1.05  (RB/STB)
   Res. Saturation         0.2           0.3  (fraction)
                        Actual     BreakThr.
              Time  31/08/2072    11/10/2014  (date d/m/y)
       PV Injected      2.2165         0.102  (fraction)
   Recovery Factor    0.622531      0.127446  (fraction)
    Water Injected     13.9403      0.641509  (MMSTB)
      Oil Produced     2.98308      0.610705  (MMSTB)
    Water Produced      10.808                (MMSTB)
```

- The results can also be analysed in tabular form, by pressing **Finish**.

  - Pressing ***Calculation|Results*** shows the detailed results.
  - Pressing ***Save|add*** save the results as ***Base Case***.
  - Pressing Plot and plotting (i) water cut evolution over time and (ii) the oil recovery factor gives the below plot.


1D Results
Calculated
Base Case
Time
PV Injected
Frontal Speed
Frontal Advance
Average Oil Rate
Water Cut
Cumulative Oil Production
Cumulative Water Production
Cumulative Water Injection
Recovery Factor
Water Saturation
(fraction)
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
03/12/2011
29/11/2027
25/11/2043
21/11/2059
Time (date d/m/y)
Calculated:Water Cut
Calculated:Recovery Factor

- Water cut is 0.99 (99% on the final date) and the recovery factor is 0.62 (read directly from the above graph).

Having established the base Case, the EOR techniques can now be assessed.

3.7.4 EOR Technique 1: Hot Water

Enter topic text here.

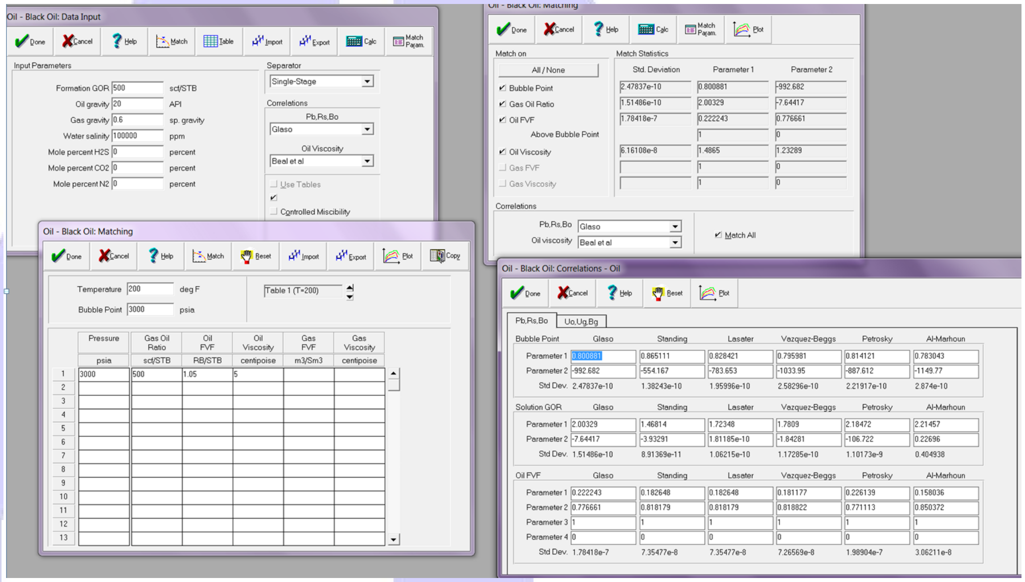
3.7.4.1 setting up the option

- Pressing Options make the following selections:
  - Fluid model type: ***Enter fluid model***
  - EOR type as ***Hot Water***.

3.7.4.2 PVT Data

Entering the PVT data

- Pressing ***PVT| Fluid Properties*** allows the user to specify (i) basic input data for the black oil model, and then by pressing ***Match*** the (ii) PVT lab data for matching can be entered.
  - Enter the data as per the below screen shots, then pressing ***Match| Calculate***, the BO models can be matched to the lab data entered.
  - Pressing match parameters allows the user to select which correlation to choose (see chapter on PVT matching for further information).
    - In this example the default correlations are used (i.e. Glaso and Bael)


Oil - Black Oil: Data Input
Done
Cancel
Help
Match
Table
Import
Export
Calc
Match Param.
Oil - Black Oil: Matching
Done
Cancel
Help
Calc
Match Param.
Plot
Oil - Black Oil: Matching
Done
Cancel
Help
Match
Reset
Import
Export
Plot
Copy
Oil - Black Oil: Correlations - Oil
Done
Cancel
Help
Reset
Plot
Pb,Rs,Bo
Uo,Ug,Bg

Input Parameters

Formation GOR 500 scf/STB
Oil gravity 20 API
Gas gravity 0.6 sp. gravity
Water salinity 100000 ppm
Mole percent H2S 0 percent
Mole percent CO2 0 percent
Mole percent N2 0 percent

Separator: Single-Stage

Correlations
Pb,Rs,Bo: Glaso
Oil Viscosity: Beal et al
☐ Use Tables
☑
☐ Controlled Miscibility

Match on

All / None

	Std. Deviation	Parameter 1	Parameter 2
☑ Bubble Point	2.47837e-10	0.800881	-992.682
☑ Gas Oil Ratio	1.51486e-10	2.00329	-7.64417
☑ Oil FVF	1.78418e-7	0.222243	0.776661
Above Bubble Point		1	0
☑ Oil Viscosity	6.16108e-8	1.4865	1.23289
☐ Gas FVF		1	0
☐ Gas Viscosity		1	0

Correlations
Pb,Rs,Bo: Glaso
Oil viscosity: Beal et al
☑ Match All

Temperature 200 deg F
Bubble Point 3000 psia
Table 1 (T=200)

	Pressure	Gas Oil Ratio	Oil FVF	Oil Viscosity	Gas FVF	Gas Viscosity
	psia	scf/STB	RB/STB	centipoise	m3/Sm3	centipoise
1	3000	500	1.05	5		
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						

Bubble Point	Glaso	Standing	Lasater	Vazquez-Beggs	Petrosky	Al-Marhoun
Parameter 1	0.800881	0.865111	0.828421	0.795981	0.814121	0.783043
Parameter 2	-992.682	-554.167	-783.653	-1033.95	-887.612	-1149.77
Std Dev.	2.47837e-10	1.38243e-10	1.95996e-10	2.58296e-10	2.21917e-10	2.874e-10

Solution GOR	Glaso	Standing	Lasater	Vazquez-Beggs	Petrosky	Al-Marhoun
Parameter 1	2.00329	1.46814	1.72348	1.7809	2.18472	2.21457
Parameter 2	-7.64417	-3.93291	1.81185e-10	-1.84281	-106.722	0.22696
Std Dev.	1.51486e-10	8.91369e-11	1.06215e-10	1.17285e-10	1.10173e-9	0.404938

Oil FVF	Glaso	Standing	Lasater	Vazquez-Beggs	Petrosky	Al-Marhoun
Parameter 1	0.222243	0.182648	0.182648	0.181177	0.226139	0.158036
Parameter 2	0.776661	0.818179	0.818179	0.818822	0.771113	0.850372
Parameter 3	1	1	1	1	1	1
Parameter 4	0	0	0	0	0	0
Std Dev.	1.78418e-7	7.35477e-8	7.35477e-8	7.26569e-8	1.98904e-7	3.06211e-8

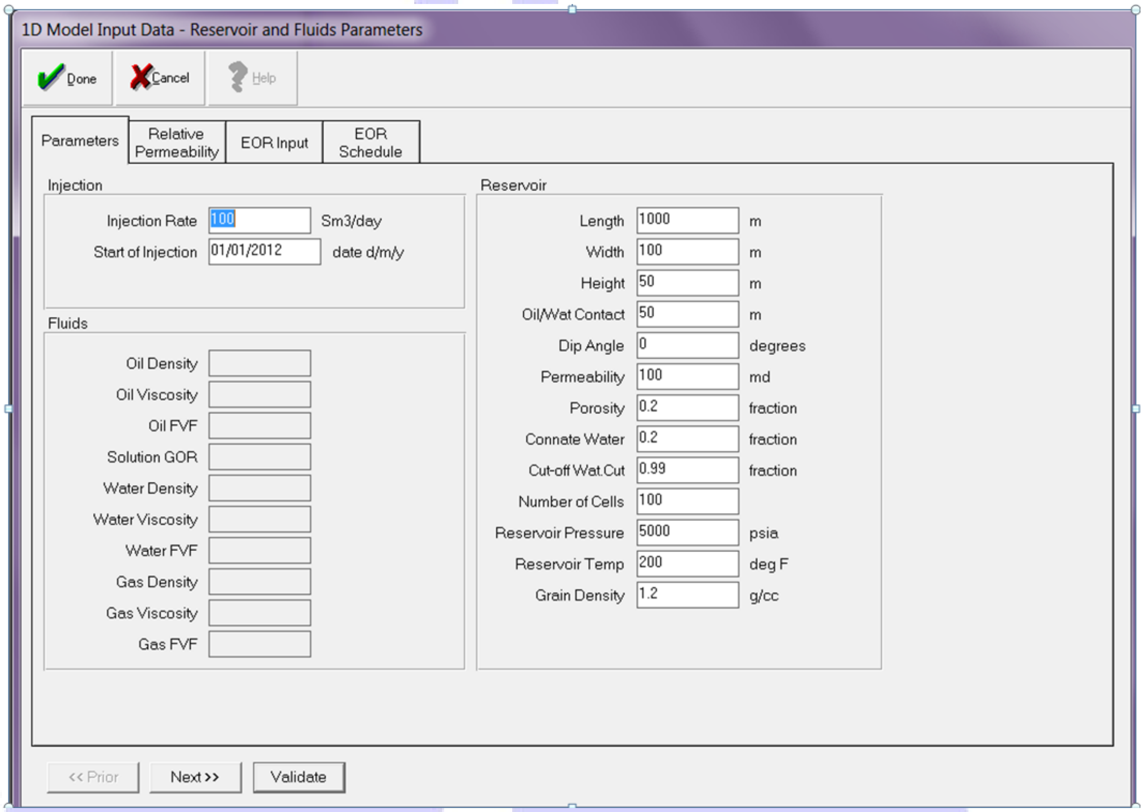
3.7.4.3 Reservoir Parameters

Entering the Reservoir Parameters

- Now that the PVT has been entered, pressing ***Input |Reservoir Parameters*** allows the EOR Data to be Entered:
  - The data required for this calculation would be:
    - Reservoir pressure and temperature for use with the Black oil models

  - The Rock specific heat
  - The amount of water added, and the water temperature.

- Enter the data as per the screen shots below:



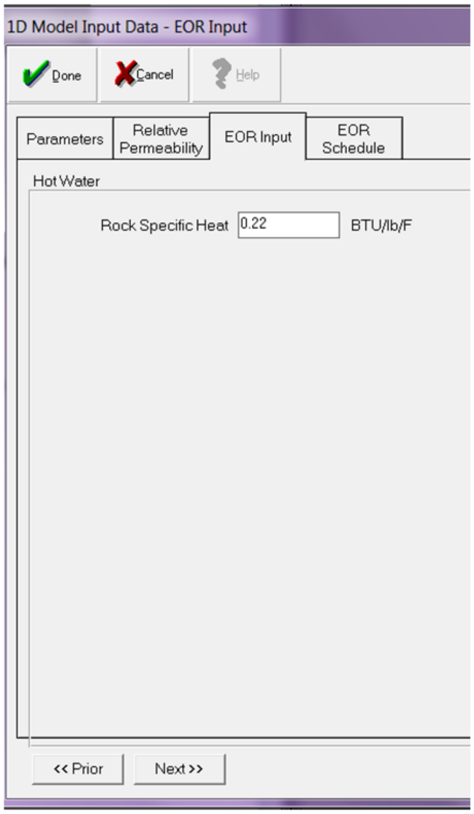
1D Model Input Data - Reservoir and Fluids Parameters

Done
Cancel
Help
Parameters
Relative Permeability
EOR Input
EOR Schedule
Injection
Fluids
Reservoir
<< Prior
Next >>
Validate

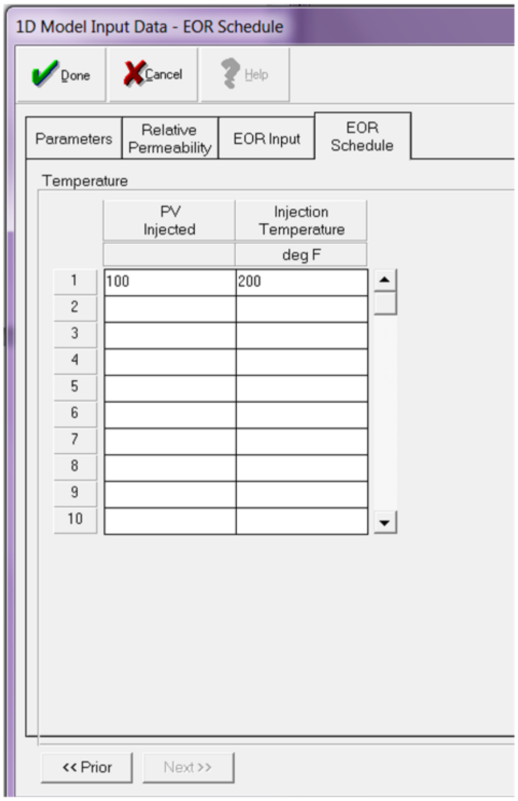
Injection Rate	100	Sm3/day
Start of Injection	01/01/2012	date d/m/y

Oil Density	
Oil Viscosity	
Oil FVF	
Solution GOR	
Water Density	
Water Viscosity	
Water FVF	
Gas Density	
Gas Viscosity	
Gas FVF	

Length	1000	m
Width	100	m
Height	50	m
Oil/Wat Contact	50	m
Dip Angle	0	degrees
Permeability	100	md
Porosity	0.2	fraction
Connate Water	0.2	fraction
Cut-off Wat.Cut	0.99	fraction
Number of Cells	100	
Reservoir Pressure	5000	psia
Reservoir Temp	200	deg F
Grain Density	1.2	g/cc


1D Model Input Data - EOR Input
Done
Cancel
Help
Parameters
Relative Permeability
EOR Input
EOR Schedule
Hot Water
<< Prior
Next >>

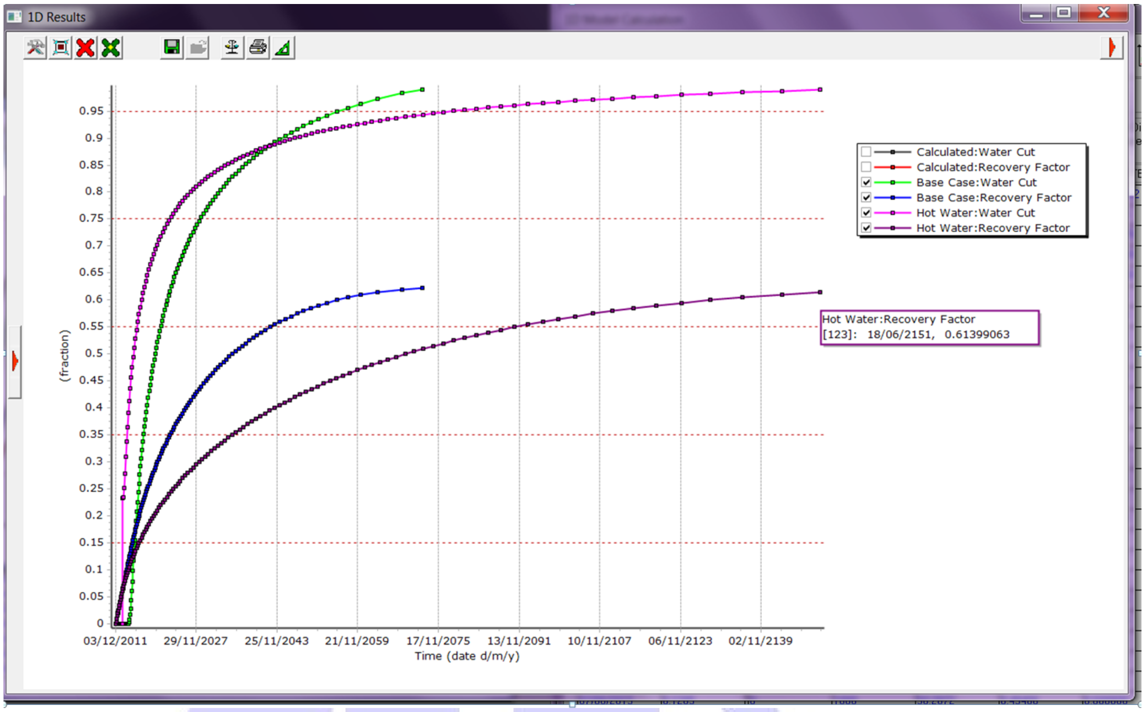
Rock Specific Heat 0.22 BTU/lb/F


1D Model Input Data - EOR Schedule
Done
Cancel
Help
Parameters
Relative Permeability
EOR Input
EOR Schedule
Temperature
<< Prior
Next >>

	PV Injected	Injection Temperature
		deg F
1	100	200
2		
3		
4		
5		
6		
7		
8		
9		
10		

3.7.4.4 Results

- Having run this, the calculation can be performed again. The results saved and compared to the base case (see diagram below)
  - It can be seen from the graph below that the production using Hot water allow a slightly lower oil recovery factor, over a longer period of time.



3.7.5 EOR Technique 2: Polymer Injection

Enter topic text here.

3.7.5.1 setting up the Option

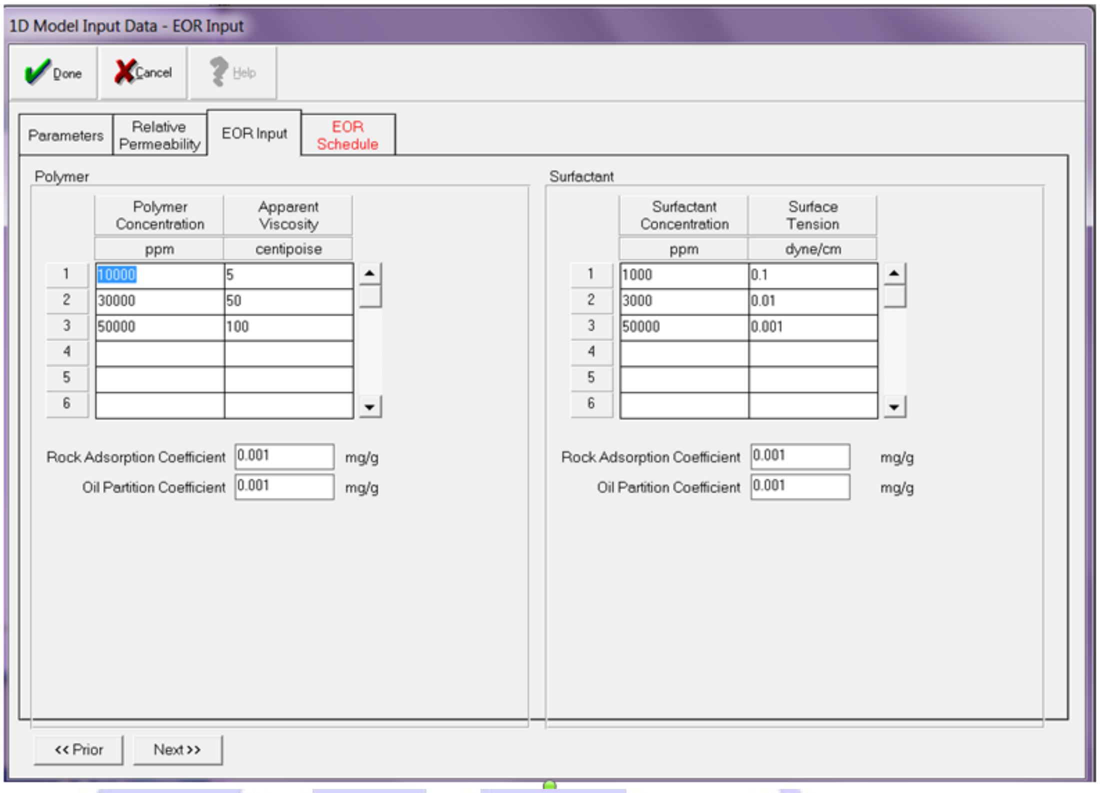
Setting-up the option

- Pressing Options make the following selections:
    - Fluid model type: ***Enter fluid properties***
    - EOR type as ***Surfactant/Polymer***.

3.7.5.2 Reservoir Parameters

Entering the Reservoir Parameters

- Pressing ***Input |Reservoir Parameters*** allows the EOR Data to be Entered:
    - Data required is the polymer and surfactant concentrations, and the relative amounts that are injected in the reservoir.
    - Enter the data as per screen shots below:


1D Model Input Data - EOR Input
Done
Cancel
Help
Parameters
Relative Permeability
EOR Input
EOR Schedule
<< Prior
Next >>

Polymer

	Polymer Concentration	Apparent Viscosity
	ppm	centipoise
1	10000	5
2	30000	50
3	50000	100
4		
5		
6		

Rock Adsorption Coefficient 0.001 mg/g

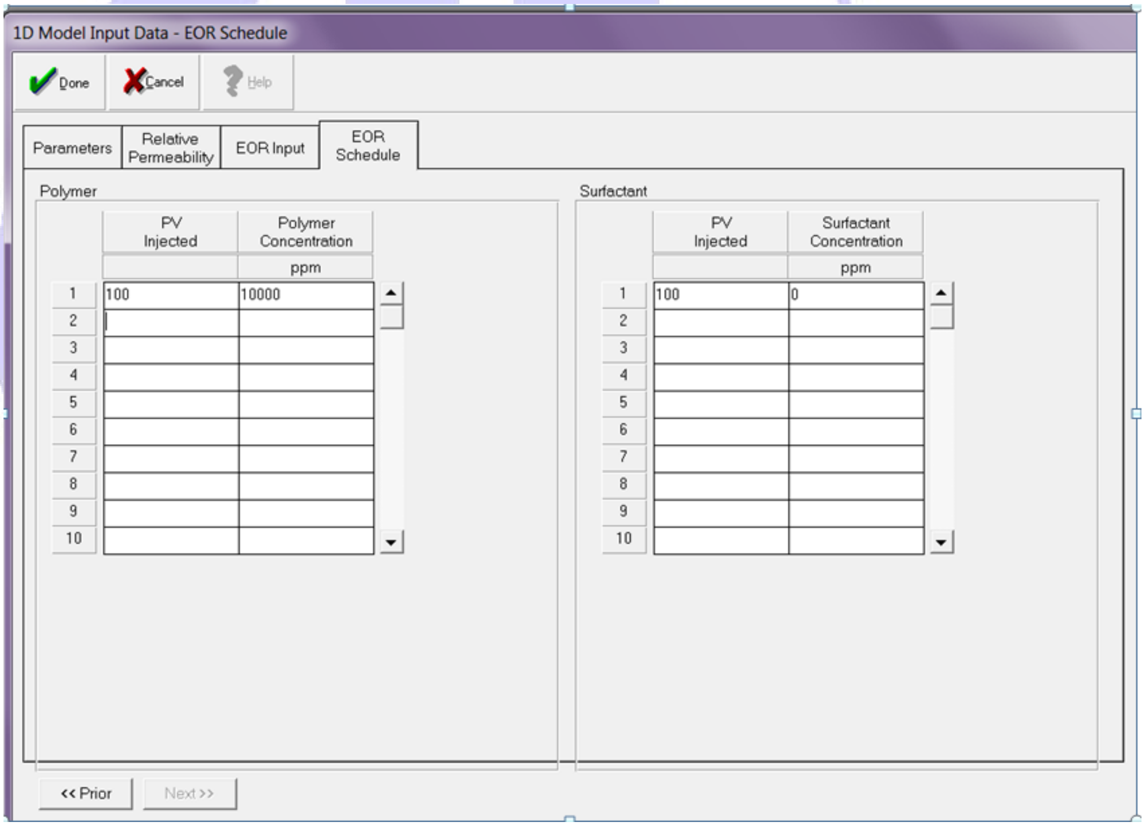
Oil Partition Coefficient 0.001 mg/g

Surfactant

	Surfactant Concentration	Surface Tension
	ppm	dyne/cm
1	1000	0.1
2	3000	0.01
3	50000	0.001
4		
5		
6		

Rock Adsorption Coefficient 0.001 mg/g

Oil Partition Coefficient 0.001 mg/g


1D Model Input Data - EOR Schedule
Done
Cancel
Help
Parameters
Relative Permeability
EOR Input
EOR Schedule
<< Prior
Next >>

Polymer

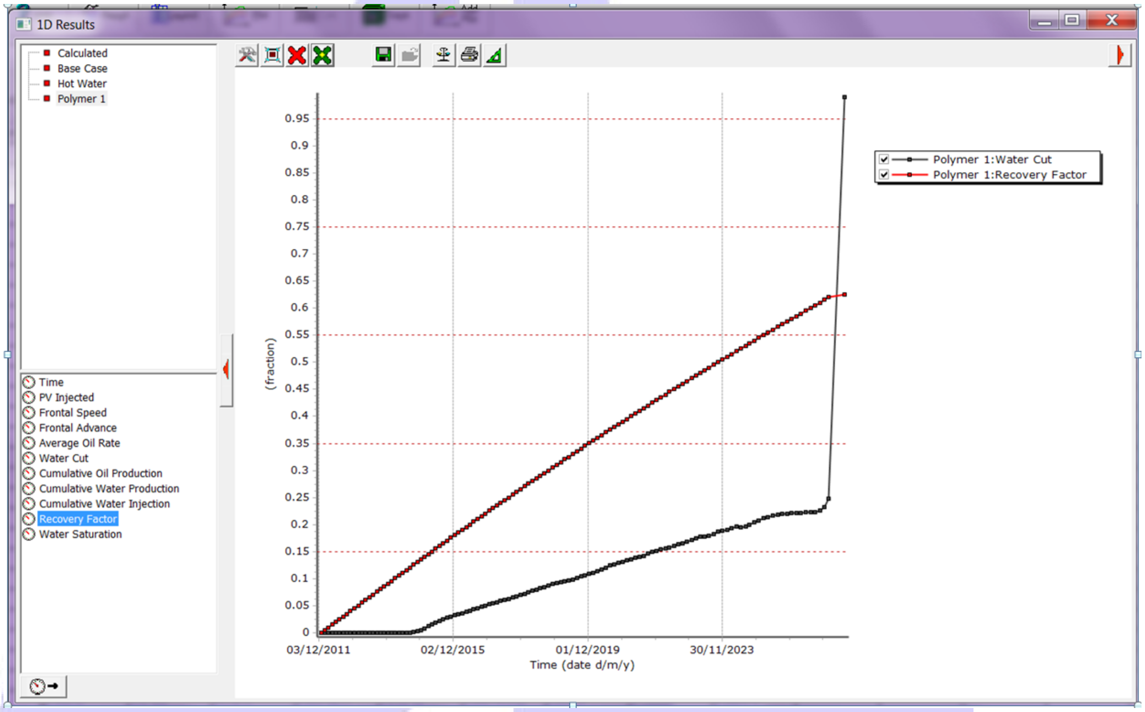
	PV Injected	Polymer Concentration
		ppm
1	100	10000
2		
3		
4		
5		
6		
7		
8		
9		
10		

Surfactant

	PV Injected	Surfactant Concentration
		ppm
1	100	0
2		
3		
4		
5		
6		
7		
8		
9		
10		

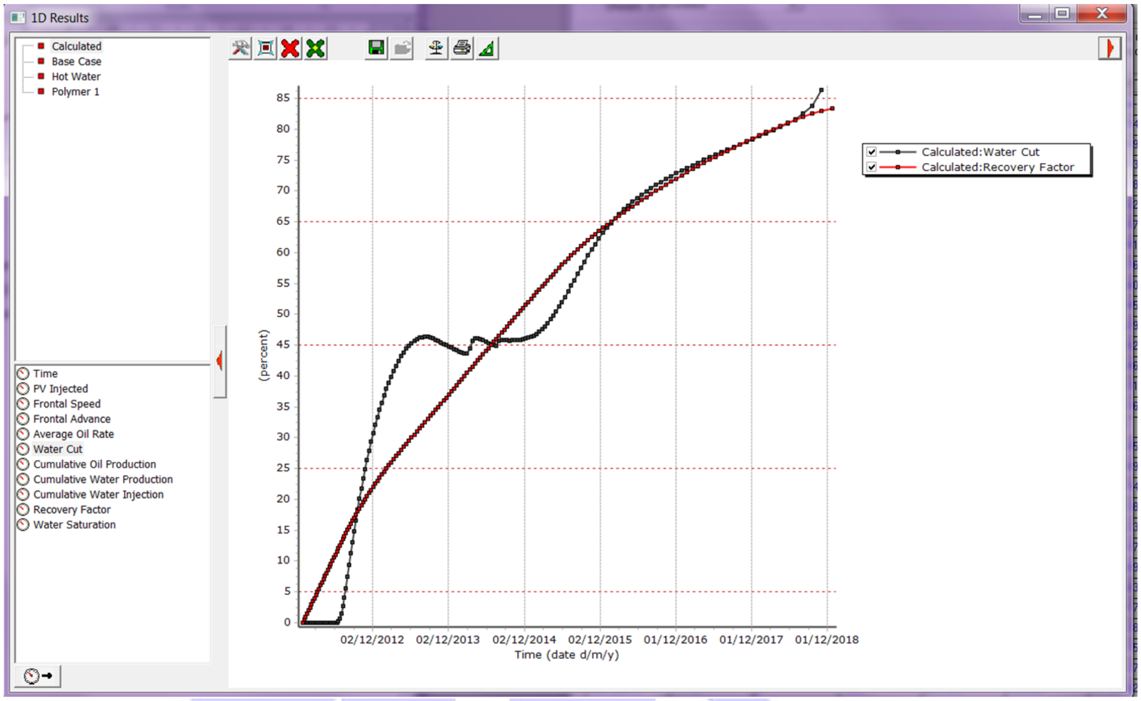
3.7.5.3 Results

- Pressing Calculation| Run simulation and pressing calculate as before allows the simulation to proceed.
- The results are saved as “Polymer 1” and compared to the base case and hot water case.
    - Recovery factor is 0.6249


1D Results
Calculated
Base Case
Hot Water
Polymer 1
Time
PV Injected
Frontal Speed
Frontal Advance
Average Oil Rate
Water Cut
Cumulative Oil Production
Cumulative Water Production
Cumulative Water Injection
Recovery Factor
Water Saturation
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
(fraction)
03/12/2011
02/12/2015
01/12/2019
30/11/2023
Time (date d/m/y)
☑ Polymer 1:Water Cut
☑ Polymer 1:Recovery Factor

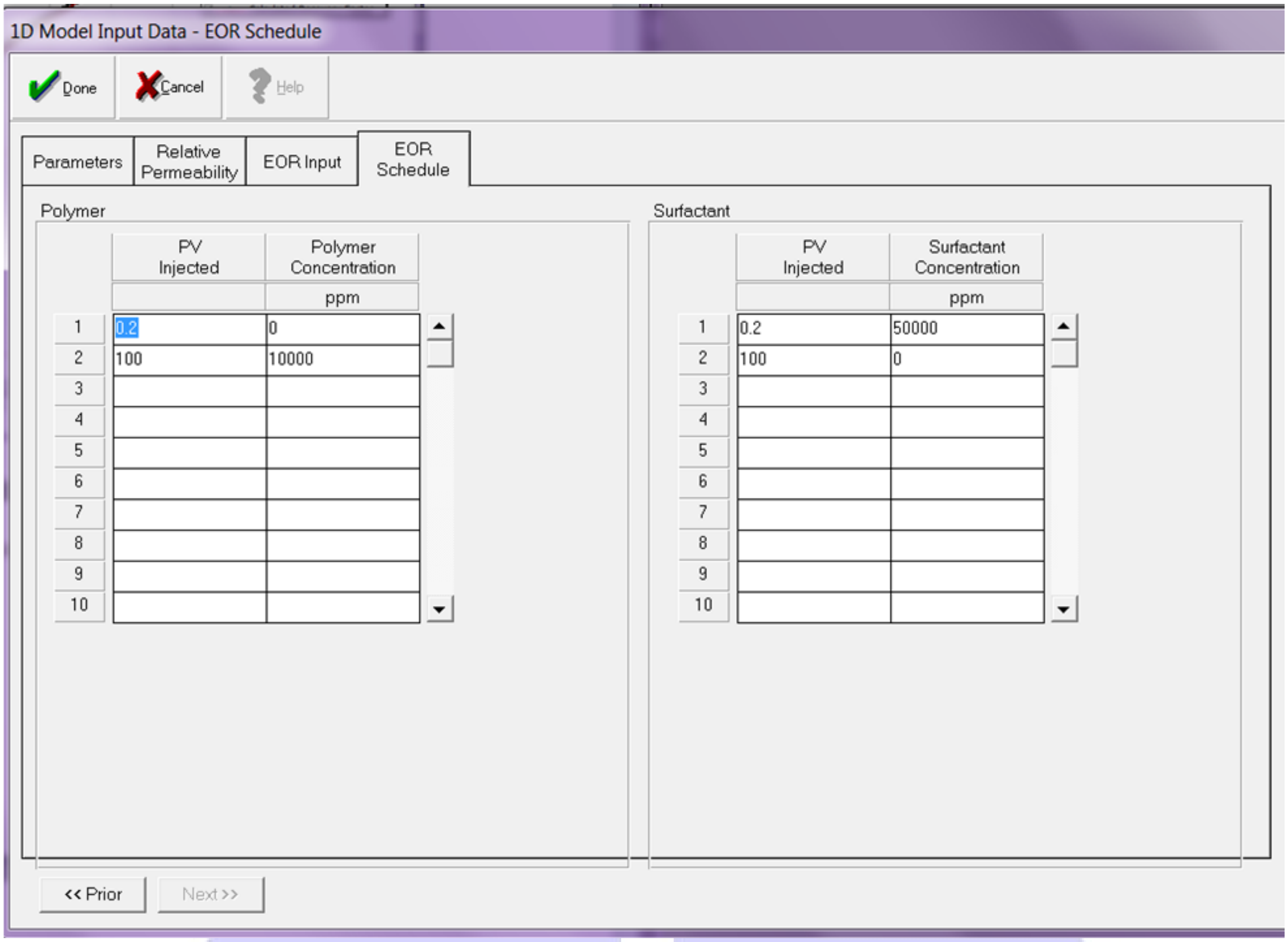
3.7.6 EOR Technique 3: Surfactant Injection

- Enter the ***Input |reservoir Parameters*** and change the polymer concentration to 0, and specify a surfactant concentration of 50,000ppm
- Re-run the calculation, save the results and compare to base case, technique 1 and 2.
    - Recovery factor is 0.83


1D Results
Calculated
Base Case
Hot Water
Polymer 1
Time
PV Injected
Frontal Speed
Frontal Advance
Average Oil Rate
Water Cut
Cumulative Oil Production
Cumulative Water Production
Cumulative Water Injection
Recovery Factor
Water Saturation
(percent)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
02/12/2012
02/12/2013
02/12/2014
02/12/2015
01/12/2016
01/12/2017
01/12/2018
Time (date d/m/y)
☑ Calculated:Water Cut
☑ Calculated:Recovery Factor

3.7.7 EOR Technique 4: Polymer & Surfactant Injection

Enter the ***Input |reservoir Parameters*** and change the polymer and surfactant concentrations accordingly:


1D Model Input Data - EOR Schedule
Done
Cancel
Help
Parameters
Relative Permeability
EOR Input
EOR Schedule
<< Prior
Next >>

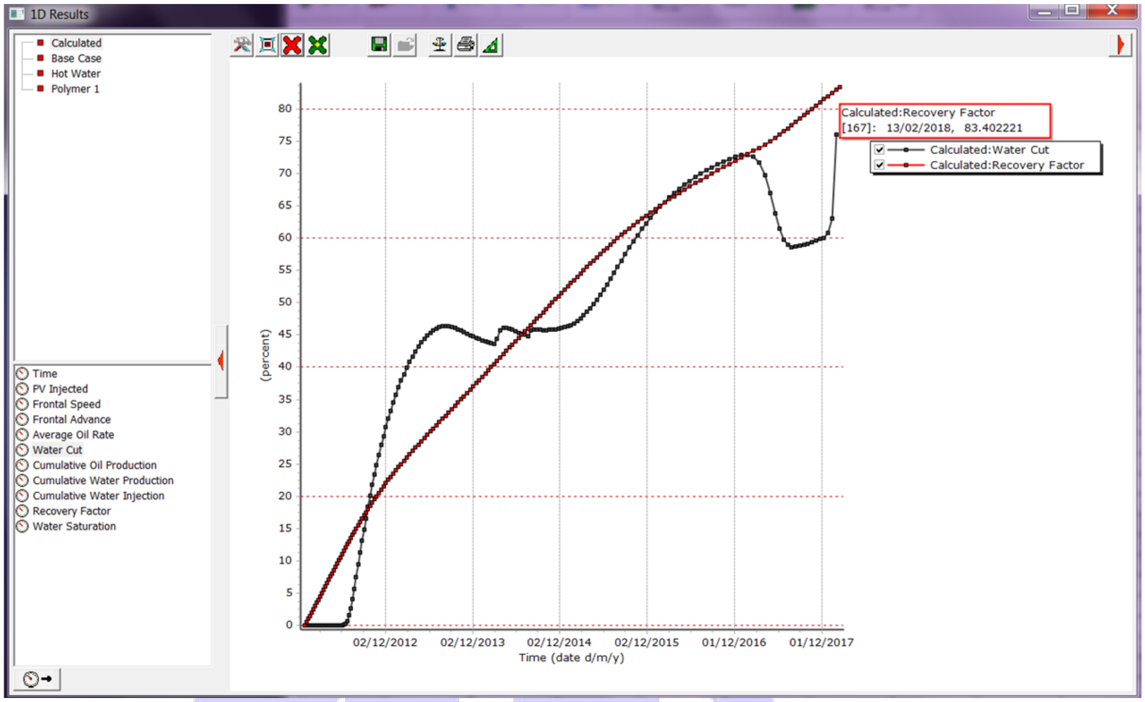
Polymer

	PV Injected	Polymer Concentration
		ppm
1	0.2	0
2	100	10000
3		
4		
5		
6		
7		
8		
9		
10		

Surfactant

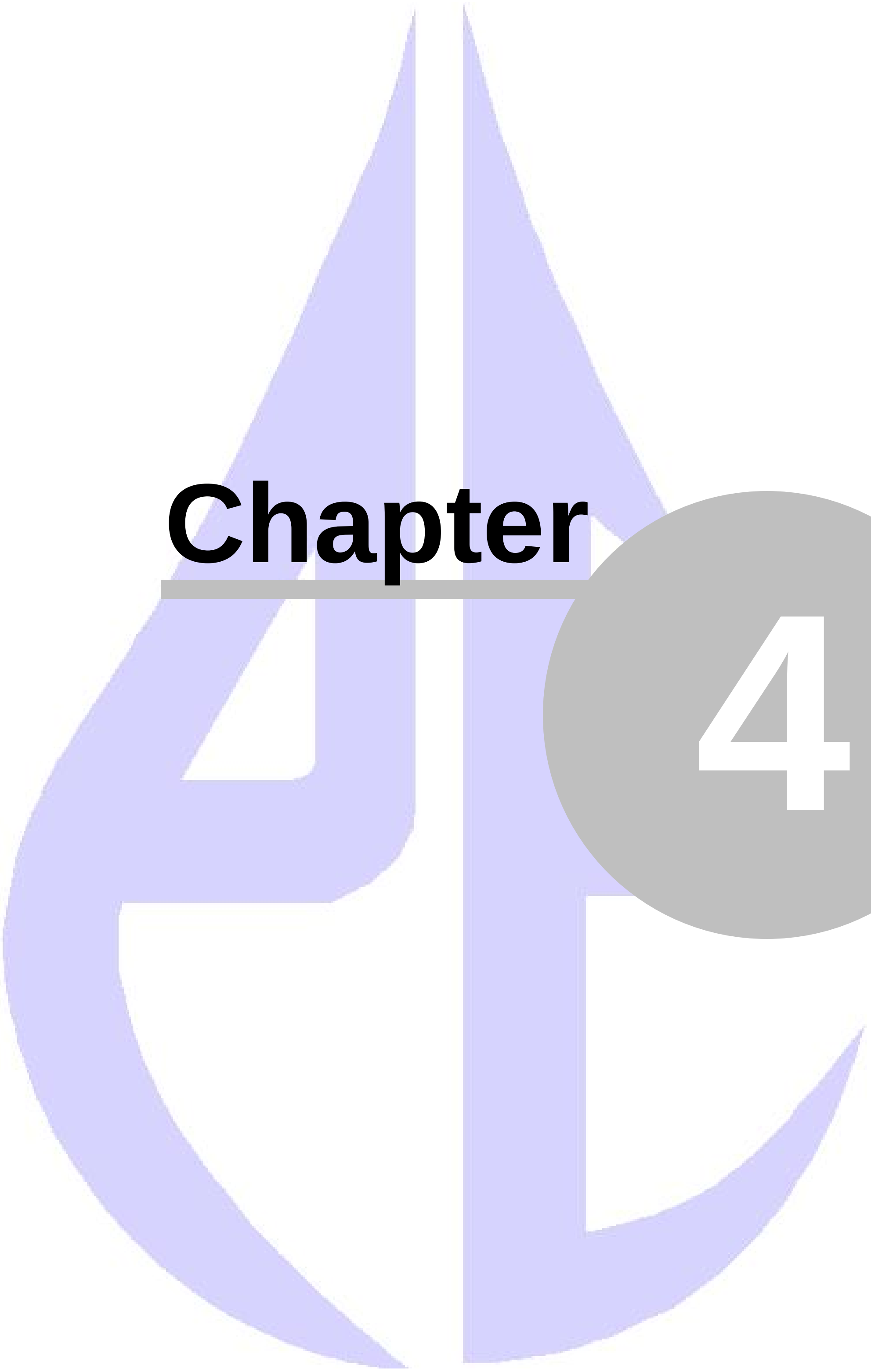
	PV Injected	Surfactant Concentration
		ppm
1	0.2	50000
2	100	0
3		
4		
5		
6		
7		
8		
9		
10		

- Re-run the model, save the results and analyse the results as before:
    - Recovery factor found to be 83.4%


1D Results
Calculated
Base Case
Hot Water
Polymer 1
Time
PV Injected
Frontal Speed
Frontal Advance
Average Oil Rate
Water Cut
Cumulative Oil Production
Cumulative Water Production
Cumulative Water Injection
Recovery Factor
Water Saturation
Calculated:Recovery Factor
[167]: 13/02/2018, 83.402221
☑ Calculated:Water Cut
☑ Calculated:Recovery Factor
(percent)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
02/12/2012
02/12/2013
02/12/2014
02/12/2015
01/12/2016
01/12/2017
Time (date d/m/y)

3.7.8 Conclusion

Using the 1d model with EOR techniques a number of different oil displacement techniques have been simulated: the conclusion of which is that the polymer and surfactant EOR techniques achieve the highest recovery and should be investigated further.



Chapter

4

4 Case Studies

In-line with the IPM8.0 release the user guide has been updated to include case studies.

The case studies describe the workflow and theory that should be followed when using real field data within MBAL.

4.1 Case Study 1

Introduction

An oil reservoir in North sea belonging to a certain company has been on production for some years.

A material balance reservoir model was designed to obtain fluid volumes in place and aquifer strength as well as to forecast short term production.

- Initial estimates from geological studies indicate a STOIIP of approximately 600MMstb
- The material balance model indicate a STOIIP of 900 MMstb.

Further investigation was carried out to validate these results: these were all in favour of the geological estimates.

4.1.1 Objectives

Objectives

The company has thus approached us to achieve the following objectives:

- Create a representative material balance model for the reservoir (history matching)
- Determine drive mechanisms
- Verify the STOIIP

Data available

Tank parameters, PVT model, Pressure and production history.

4.1.2 Approach

Approach

When setting up any MBAL model, the key to a good history match is to start with a single tank and build upon this in a step by step fashion (depending on details available and the overall knowledge of the project).

With this approach, the engineer can gradually understand the response of the model, for instance in terms of pressure signatures etc. This can then be linked this with the actual behaviour of the field, and subsequently the engineer can adjust the model (as required) to obtain a matched model.

This approach will be illustrated in this case study that shows how a real reservoir system was modelled in MBAL and history matched.

Using MBAL to achieve the Objectives (Theory)

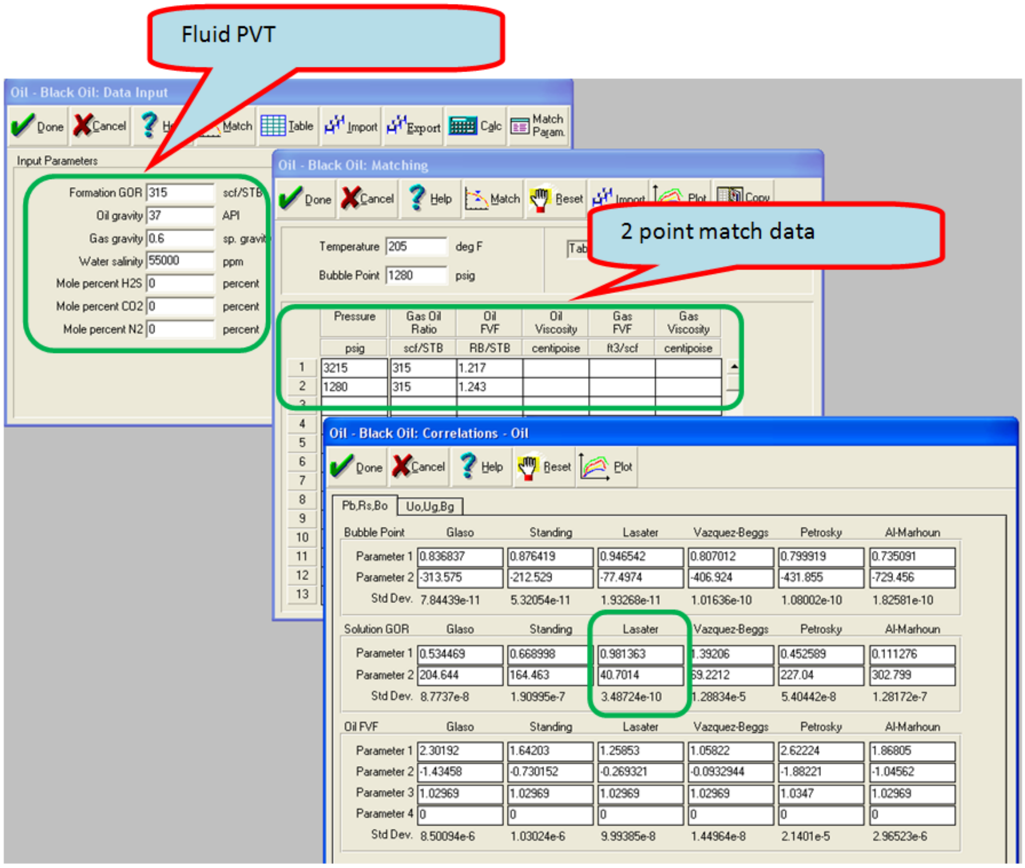
Material balance simply put is a volume balance on the reservoir. By taking into account fluid PVT relationship, pressure and production history and knowledge of tank parameters, a material balance model can be created and matched to the actual reservoir behaviour.

History matching in MBAL is performed using the Graphical and analytical methods. The graphical methods are the traditional history matching techniques which re-arrange the material balance equation (F-We = NEt) to obtain a straight line relationship when plotted graphically. From the relationships, the key reservoir drive mechanisms as well as fluid volumes in place, aquifer influx e.t.c. can be estimated. There are a variety of graphical methods and the most recommended for use is that by Campbell (for oils) and Cole (for gas). A good review of these graphical methods can be found in Pletcher's paper – SPE 62882.

Campbell equation re-expresses the material balance relationship as (F – We)/ Et = N. This means a plot of (F-We)/Et against some other quantity e.g. Cummulative production (Np), time e.t.c should result in a straight line equal to N. By analysing the signatures on the Campbell (or Cole plots), the engineer can infer if certain drive mechanisms (acting energy) need to be included in the model or have been over-estimated etc.

4.1.3 PVT

At the heart of a successful MBAL history match is the validity of the PVT model. The PVT model should be properly matched to measured data and it should be consistent with the production and pressure history. Below shows the PVT input parameters and match data for the case under review. The PVT match indicates that Lasater correlation is the best correlation for Oil FVF and the profile above bubble point pressure is shown. This can be seen from the match parameters calculated which fall within the recommended ranges – Parameter 1+/- 10% and Parameter 2 close to zero.


Fluid PVT
2 point match data
Oil - Black Oil: Data Input
Done
Cancel
Help
Match
Table
Import
Export
Calc
Match Param.
Oil - Black Oil: Matching
Done
Cancel
Help
Match
Reset
Import
Plot
Copy
Tab
Oil - Black Oil: Correlations - Oil
Done
Cancel
Help
Reset
Plot
Pb,Rs,Bo
Uo,Ug,Bg

Input Parameters

Formation GOR	315	scf/STB
Oil gravity	37	API
Gas gravity	0.6	sp. gravit
Water salinity	55000	ppm
Mole percent H2S	0	percent
Mole percent CO2	0	percent
Mole percent N2	0	percent

Temperature 205 deg F
Bubble Point 1280 psig

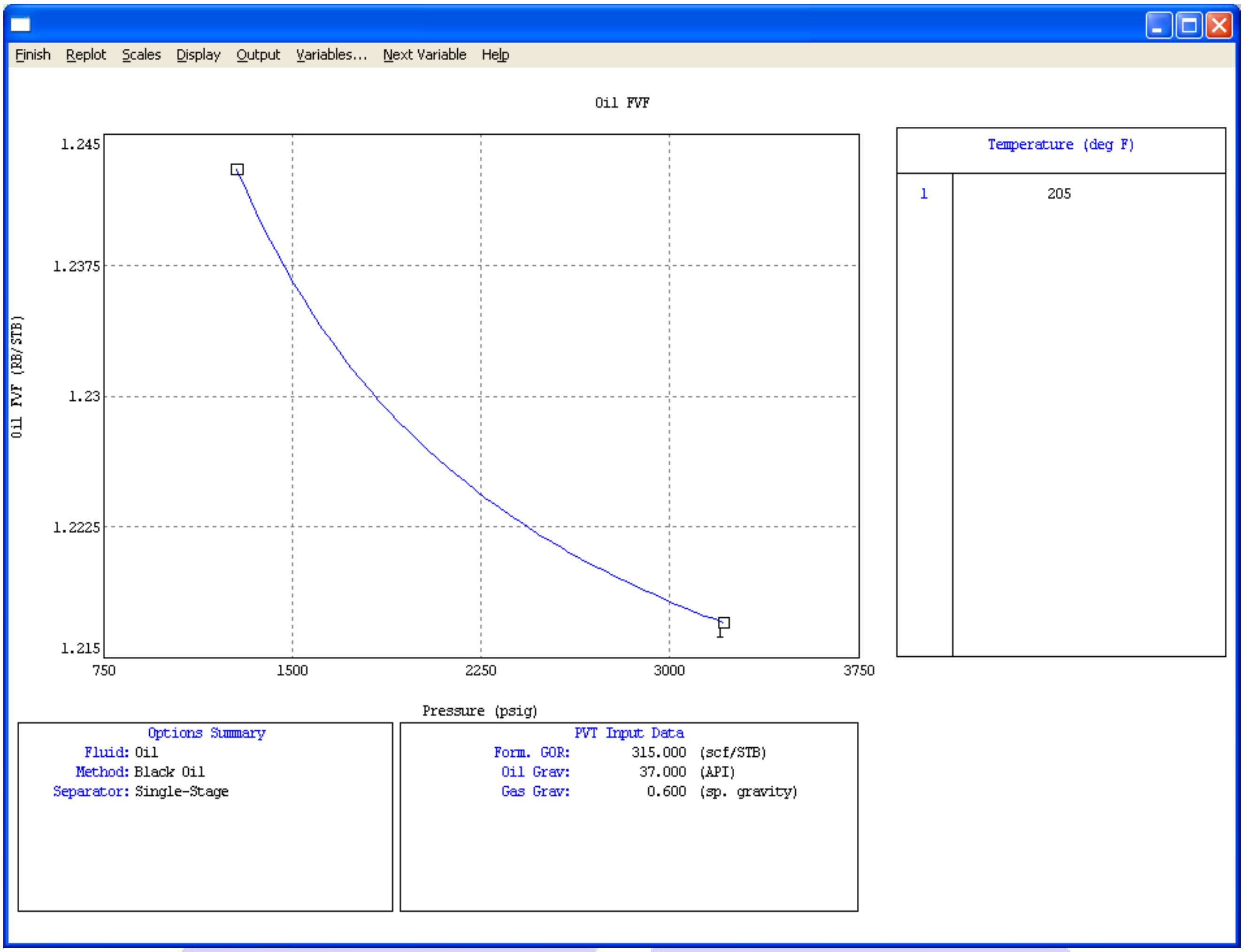
	Pressure	Gas Oil Ratio	Oil FVF	Oil Viscosity	Gas FVF	Gas Viscosity
	psig	scf/STB	RB/STB	centipoise	ft3/scf	centipoise
1	3215	315	1.217			
2	1280	315	1.243			
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						

Bubble Point	Glaso	Standing	Lasater	Vazquez-Beggs	Petrosky	Al-Marhoun
Parameter 1	0.836837	0.876419	0.946542	0.807012	0.799919	0.735091
Parameter 2	-313.575	-212.529	-77.4974	-406.924	-431.855	-729.456
Std Dev.	7.84439e-11	5.32054e-11	1.93268e-11	1.01636e-10	1.08002e-10	1.82581e-10

Solution GOR	Glaso	Standing	Lasater	Vazquez-Beggs	Petrosky	Al-Marhoun
Parameter 1	0.534469	0.668998	0.981363	1.39206	0.452589	0.111276
Parameter 2	204.644	164.463	40.7014	69.2212	227.04	302.799
Std Dev.	8.7737e-8	1.90995e-7	3.48724e-10	1.28834e-5	5.40442e-8	1.28172e-7

Oil FVF	Glaso	Standing	Lasater	Vazquez-Beggs	Petrosky	Al-Marhoun
Parameter 1	2.30192	1.64203	1.25853	1.05822	2.62224	1.86805
Parameter 2	-1.43458	-0.730152	-0.269321	-0.0932944	-1.88221	-1.04562
Parameter 3	1.02969	1.02969	1.02969	1.02969	1.0347	1.02969
Parameter 4	0	0	0	0	0	0
Std Dev.	8.50094e-6	1.03024e-6	9.99385e-8	1.44964e-8	2.1401e-5	2.96523e-6

Below is a plot of the matched FVF showing the profile above bubble point.


Finish Replot Scales Display Output Variables... Next Variable Help
Oil FVF
1.245
1.2375
1.23
1.2225
1.215
Oil FVF (RB/STB)
750
1500
2250
3000
3750
Pressure (psig)

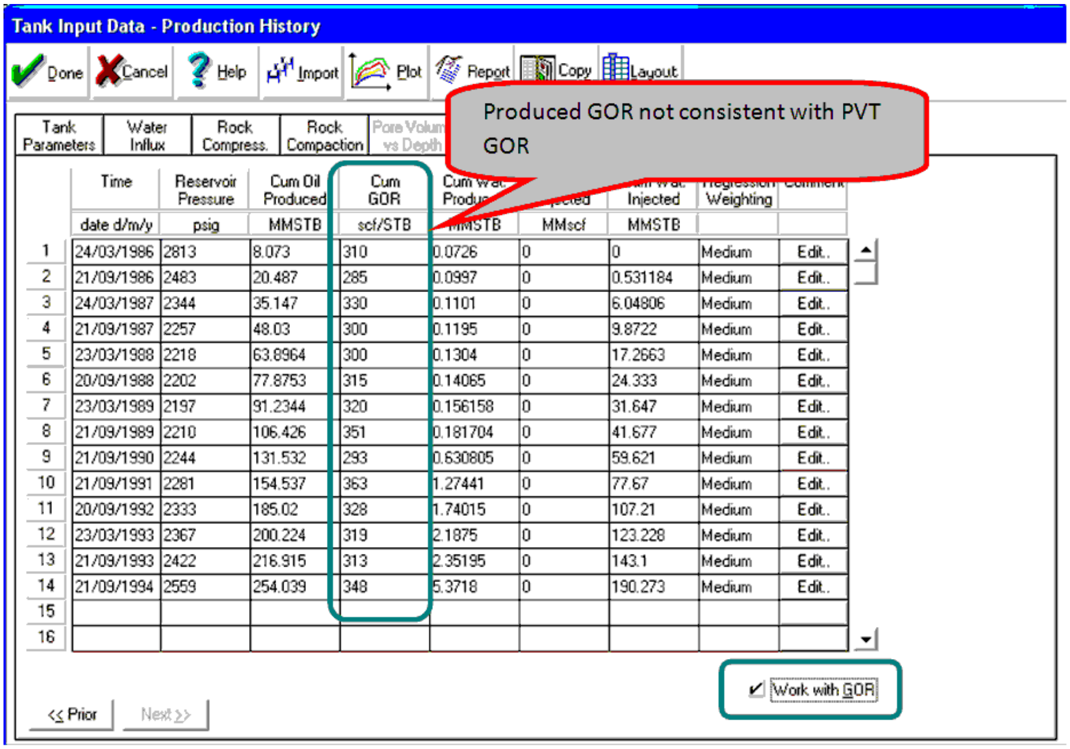
	Temperature (deg F)
1	205

Options Summary
Fluid: Oil
Method: Black Oil
Separator: Single-Stage

PVT Input Data
Form. GOR: 315.000 (scf/STB)
Oil Grav: 37.000 (API)
Gas Grav: 0.600 (sp. gravity)

The tank parameters are defined in the model and initial STOIIP estimates from geology indicate 600MMstb. A major objective of the modelling review is to confirm this geological value and also estimate aquifer strength.

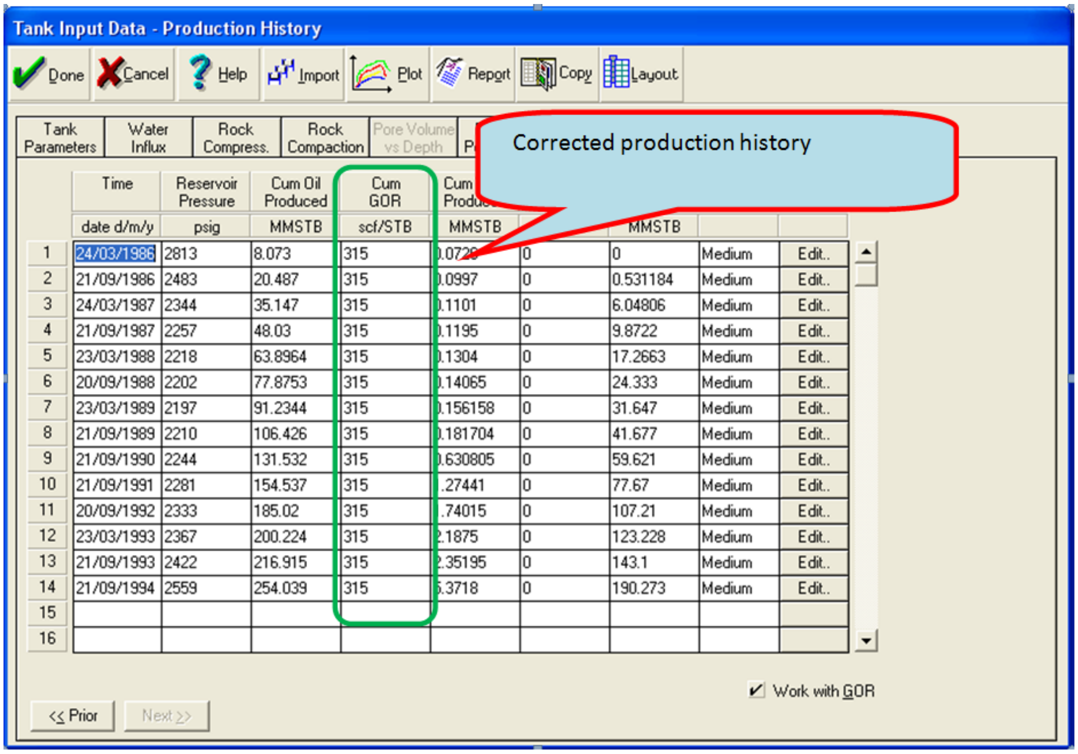
Before history matching, it is recommended to ensure the production history is consistent with the PVT data. The PVT data suggests that bubble point = 1280psi and GOR = 315scf/stb. However, the production history data shows GOR values which are not consistent with the PVT. The production history was then corrected to reflect this.


Tank Input Data - Production History
Done
Cancel
Help
Import
Plot
Report
Copy
Layout
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volum vs Depth
<< Prior
Next >>

Produced GOR not consistent with PVT GOR

	Time	Reservoir Pressure	Cum Oil Produced	Cum GOR	Cum Wat. Produ	jected	Cum Wat. Injected	Regression Weighting	Comment
	date d/m/y	psig	MMSTB	scf/STB	MMSTB	MMscf	MMSTB		
1	24/03/1986	2813	8.073	310	0.0726	0	0	Medium	Edit..
2	21/09/1986	2483	20.487	285	0.0997	0	0.531184	Medium	Edit..
3	24/03/1987	2344	35.147	330	0.1101	0	6.04806	Medium	Edit..
4	21/09/1987	2257	48.03	300	0.1195	0	9.8722	Medium	Edit..
5	23/03/1988	2218	63.8964	300	0.1304	0	17.2663	Medium	Edit..
6	20/09/1988	2202	77.8753	315	0.14065	0	24.333	Medium	Edit..
7	23/03/1989	2197	91.2344	320	0.156158	0	31.647	Medium	Edit..
8	21/09/1989	2210	106.426	351	0.181704	0	41.677	Medium	Edit..
9	21/09/1990	2244	131.532	293	0.630805	0	59.621	Medium	Edit..
10	21/09/1991	2281	154.537	363	1.27441	0	77.67	Medium	Edit..
11	20/09/1992	2333	185.02	328	1.74015	0	107.21	Medium	Edit..
12	23/03/1993	2367	200.224	319	2.1875	0	123.228	Medium	Edit..
13	21/09/1993	2422	216.915	313	2.35195	0	143.1	Medium	Edit..
14	21/09/1994	2559	254.039	348	5.3718	0	190.273	Medium	Edit..
15									
16									

☑ Work with GOR


Done
Cancel
Help
Import
Plot
Report
Copy
Layout
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
P
<< Prior
Next >>

Tank Input Data - Production History

Corrected production history

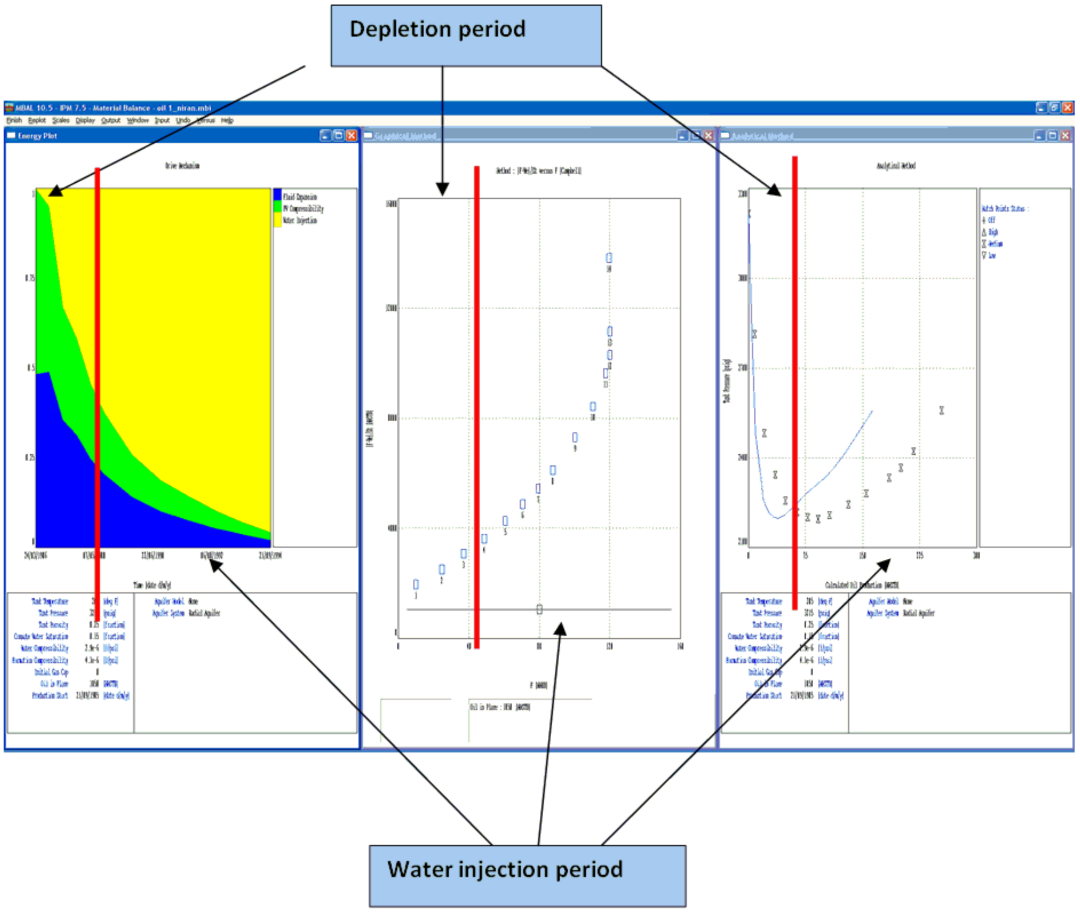
	Time	Reservoir Pressure	Cum Oil Produced	Cum GOR	Cum Produ				
	date d/m/y	psig	MMSTB	scf/STB	MMSTB		MMSTB		
1	24/03/1986	2813	8.073	315	.0729	0	0	Medium	Edit..
2	21/09/1986	2483	20.487	315	.0997	0	0.531184	Medium	Edit..
3	24/03/1987	2344	35.147	315	.1101	0	6.04806	Medium	Edit..
4	21/09/1987	2257	48.03	315	.1195	0	9.8722	Medium	Edit..
5	23/03/1988	2218	63.8964	315	.1304	0	17.2663	Medium	Edit..
6	20/09/1988	2202	77.8753	315	.14065	0	24.333	Medium	Edit..
7	23/03/1989	2197	91.2344	315	.156158	0	31.647	Medium	Edit..
8	21/09/1989	2210	106.426	315	.181704	0	41.677	Medium	Edit..
9	21/09/1990	2244	131.532	315	.630805	0	59.621	Medium	Edit..
10	21/09/1991	2281	154.537	315	.27441	0	77.67	Medium	Edit..
11	20/09/1992	2333	185.02	315	.74015	0	107.21	Medium	Edit..
12	23/03/1993	2367	200.224	315	2.1875	0	123.228	Medium	Edit..
13	21/09/1993	2422	216.915	315	2.35195	0	143.1	Medium	Edit..
14	21/09/1994	2559	254.039	315	5.3718	0	190.273	Medium	Edit..
15									
16									

☑ Work with GOR

4.1.4 History Matching

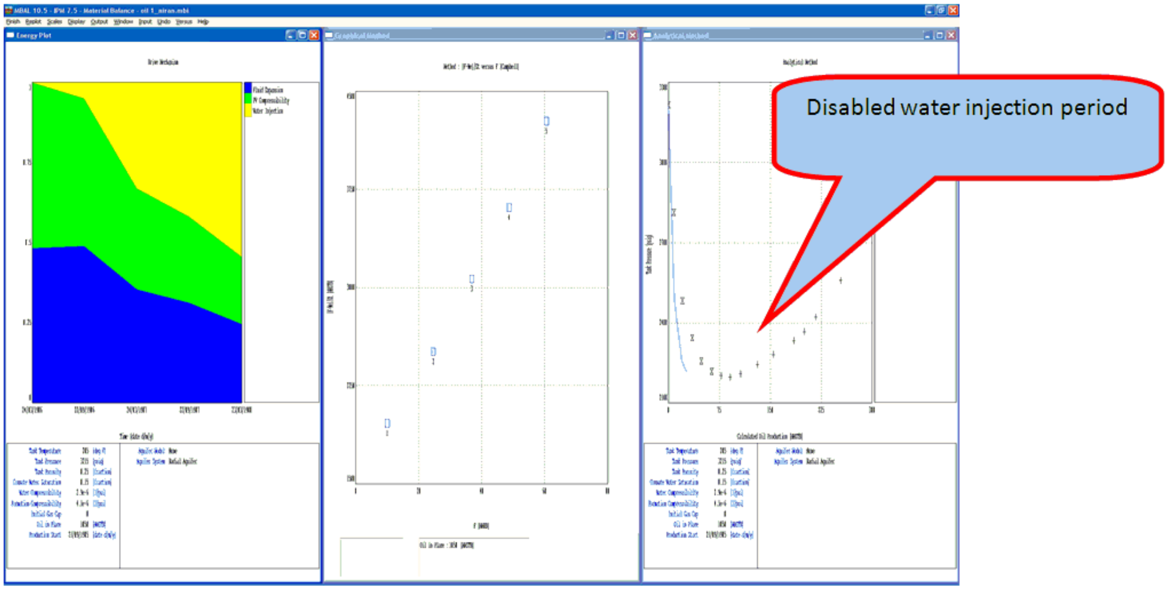
With this done, the history match process was initiated.

The history match module shows the energy plots, graphical plots and analytical plots.



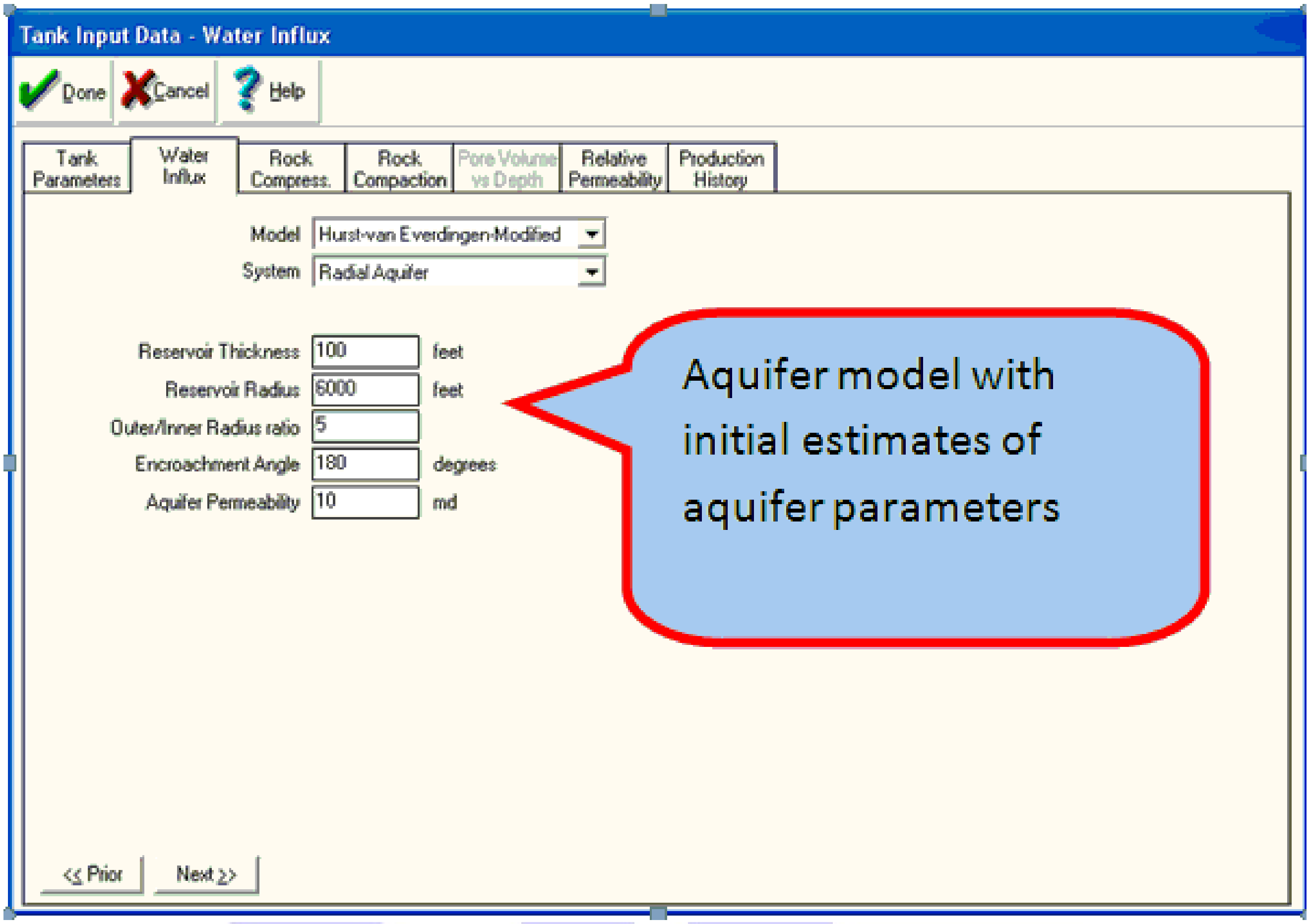
From the graphical plot, it is clear that at early time, there is depletion and later in reservoir life, water injection, which causes marked change in slope on the graphical plot. Estimating the original fluid volumes in place from a material balance approach is only possible when the reservoir pressures can respond to volumes withdrawn i.e. mainly during the depletion process. Hence, the later history points where water injection is the main drive mechanism are isolated from the analysis to focus on the early period.

WHAT DO THESE RED LINES MEAN???????????


MBAL 10.5 - IPM 7.5 - Material Balance - oil 1_niran.mbi
Finish Replot Scales Display Output Window Input Undo Versus Help
Energy Plot
Fluid Expansion
PV Compressibility
Water Injection
Graphical Method
Analytical Method

Disabled water injection period

The upwards-trending signature on the Campbell plot indicates that some energy is acting on the model which is most likely the effect of an infinite acting aquifer. An aquifer model is then included into the model and the history match calculation re-done.


Tank Input Data - Water Influx
Done
Cancel
Help
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
<< Prior
Next >>

Model Hurst-van Everdingen-Modified

System Radial Aquifer

Reservoir Thickness 100 feet

Reservoir Radius 6000 feet

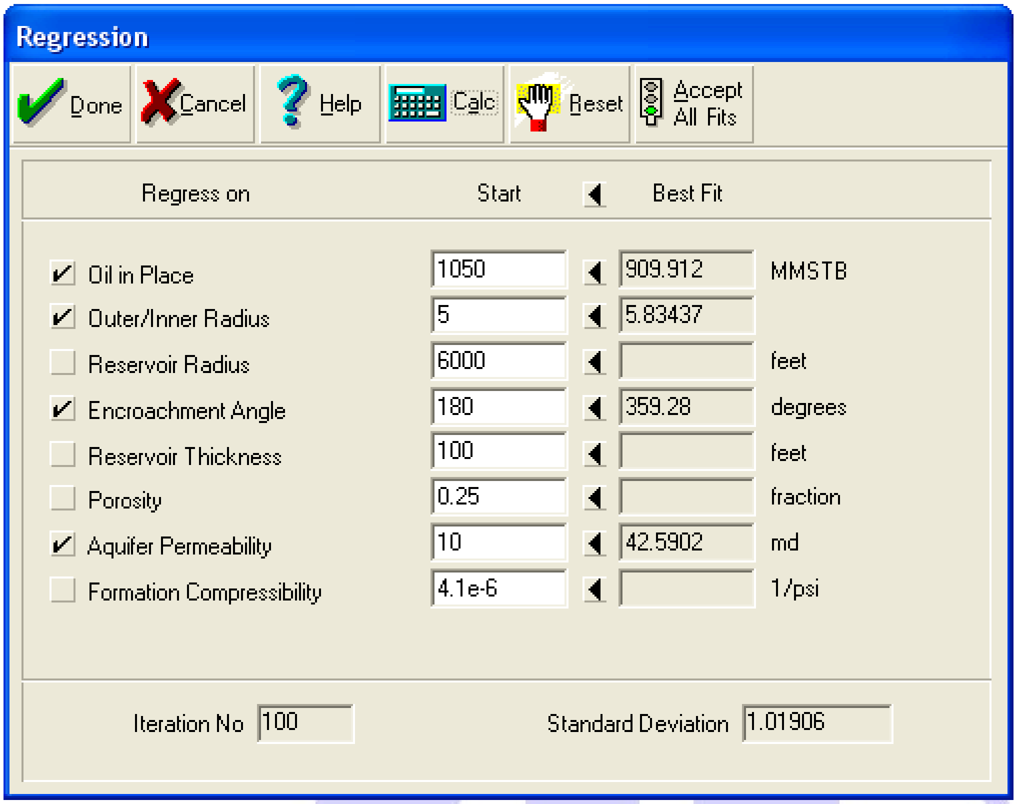
Outer/Inner Radius ratio 5

Encroachment Angle 180 degrees

Aquifer Permeability 10 md

Aquifer model with initial estimates of aquifer parameters

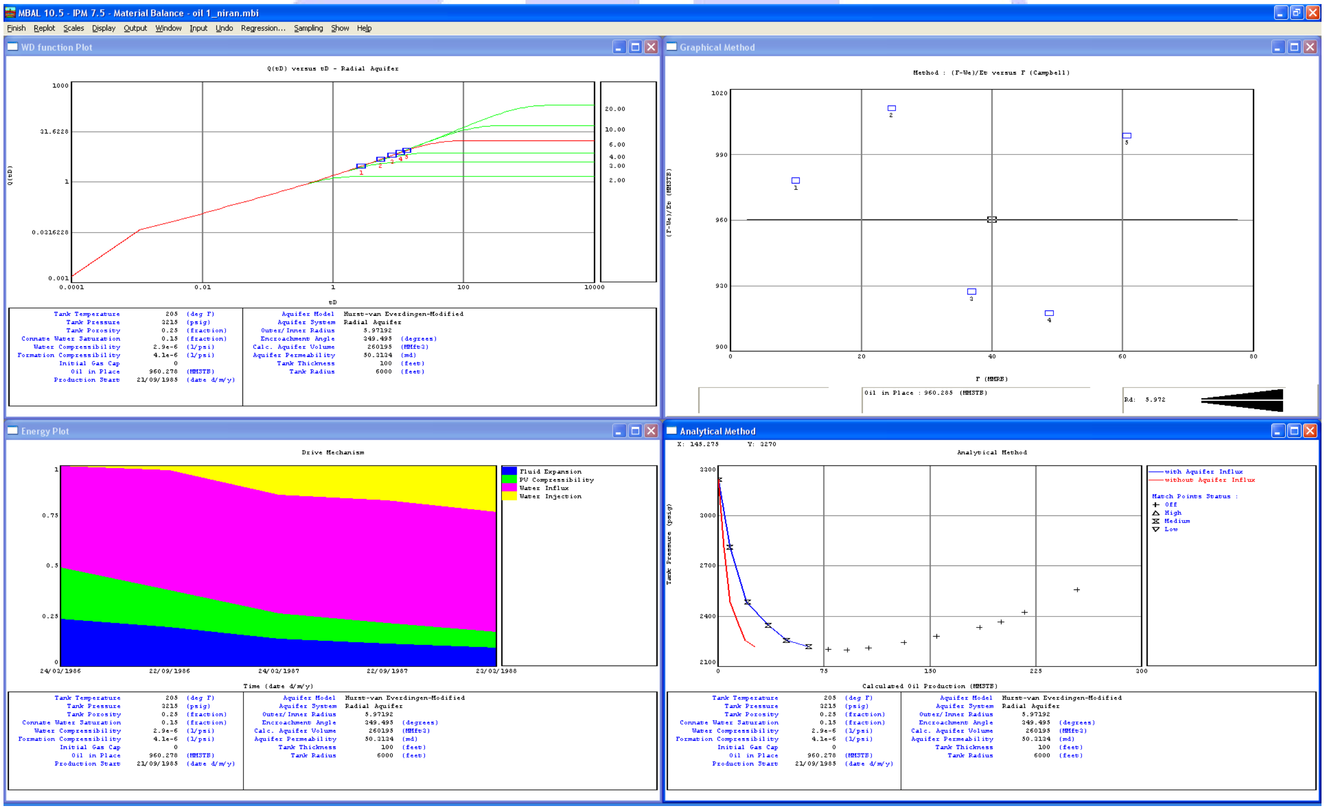
From the regression, the analytical plot shows the calculated STOIIP = 900MMstb. This is very different from the estimates from geology (600MMstb) and it became necessary to review the model further


Regression
Done
Cancel
Help
Calc
Reset
Accept All Fits

Regress on	Start	Best Fit	
☑ Oil in Place	1050	909.912	MMSTB
☑ Outer/Inner Radius	5	5.83437	
☐ Reservoir Radius	6000		feet
☑ Encroachment Angle	180	359.28	degrees
☐ Reservoir Thickness	100		feet
☐ Porosity	0.25		fraction
☑ Aquifer Permeability	10	42.5902	md
☐ Formation Compressibility	4.1e-6		1/psi

Iteration No 100

Standard Deviation 1.01906


MBAL 10.5 - IPM 7.5 - Material Balance - oil 1_niran.mbi
Finish Replot Scales Display Output Window Input Undo Regression... Sampling Show Help
WD function Plot
Q(tD) versus tD - Radial Aquifer
Q(tD)
tD
1000
31.6228
1
0.0316228
0.001
0.0001
0.01
1
100
10000
20.00
10.00
6.00
4.00
3.00
2.00
Graphical Method
Method : (F-We)/Et versus F (Campbell)
(F-We)/Et (MMSTB)
F (MMRB)
1020
990
960
930
900
0
20
40
60
80
1
2
3
4
5
Energy Plot
Drive Mechanism
Time (date d/m/y)
1
0.75
0.5
0.25
0
24/03/1986
22/09/1986
24/03/1987
22/09/1987
22/03/1988
Fluid Expansion
PV Compressibility
Water Influx
Water Injection
Analytical Method
Tank Pressure (psig)
Calculated Oil Production (MMSTB)
3300
3000
2700
2400
2100
0
75
150
225
300
with Aquifer Influx
without Aquifer Influx
Match Points Status :
Off
High
Medium
Low

Oil in Place : 960.285 (MMSTB)

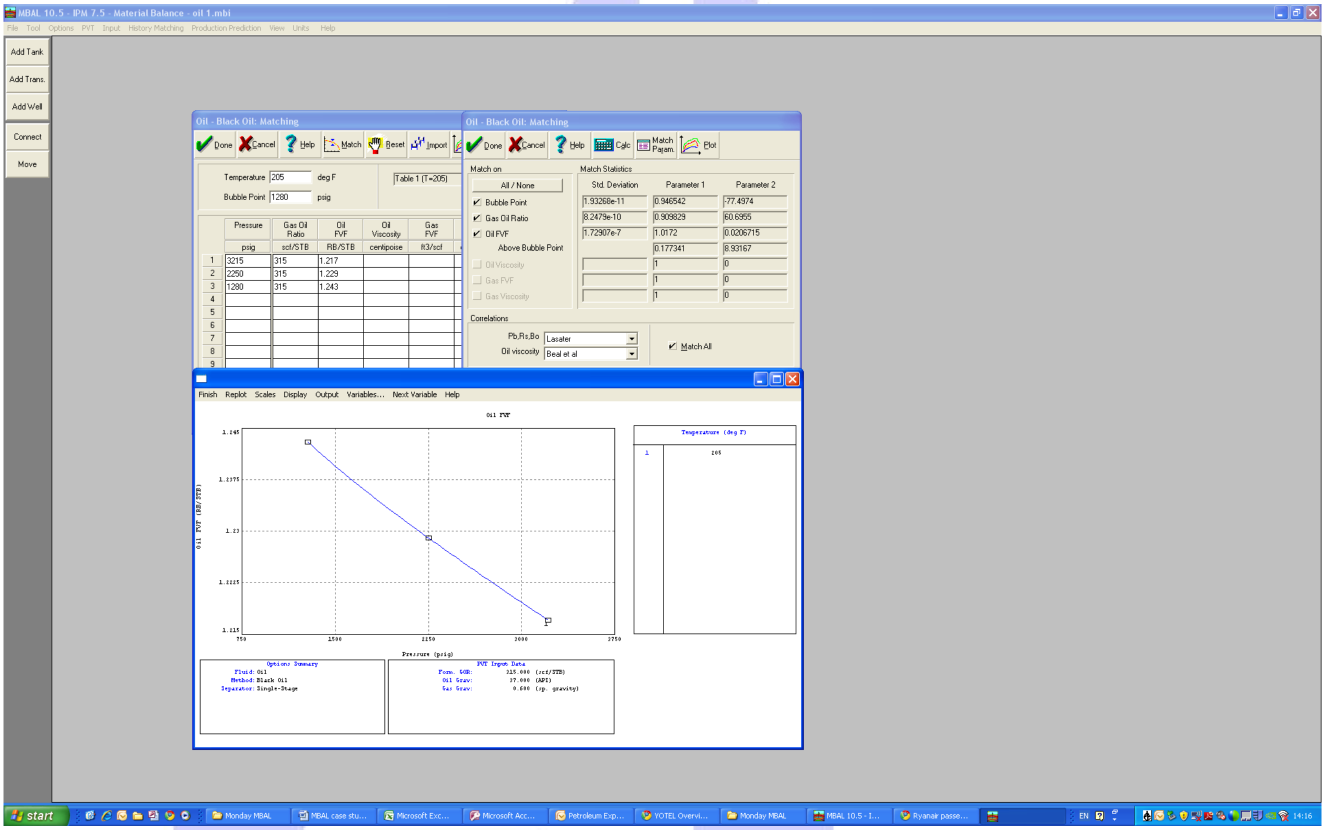
Rd: 5.972

X: 145.275 Y: 3270

Tank Temperature	205	(deg F)	Aquifer Model	Hurst-van Everdingen-Modified	
Tank Pressure	3215	(psig)	Aquifer System	Radial Aquifer	
Tank Porosity	0.25	(fraction)	Outer/ Inner Radius	5.97192	
Connate Water Saturation	0.15	(fraction)	Encroachment Angle	349.495	(degrees)
Water Compressibility	2.9e-6	(1/psi)	Calc. Aquifer Volume	260195	(MMft3)
Formation Compressibility	4.1e-6	(1/psi)	Aquifer Permeability	50.3134	(md)
Initial Gas Cap	0		Tank Thickness	100	(feet)
Oil in Place	960.278	(MMSTB)	Tank Radius	6000	(feet)
Production Start	21/09/1985	(date d/m/y)			

Back to the PVT data, a review of the PVT report provided an extra point for fluid properties above bubble point pressure. Matching the PVT with this extra point, changed the slope of the oil FVF above bubble point and hence changing the fluid compressibility. Note that Fluid volumes in place is a direct function of oil expansion which is a function of the gradient of the Oil FVF.

4.1.5 Analysis & Conclusion


MBAL 10.5 - IPM 7.5 - Material Balance - oil 1.mbi
File Tool Options PVT Input History Matching Production Prediction View Units Help
Add Tank
Add Trans.
Add Well
Connect
Move
Oil - Black Oil: Matching
Done Cancel Help Match Reset Import
Done Cancel Help Calc Match Param. Plot
Finish Replot Scales Display Output Variables... Next Variable Help
Oil FVF
Oil FVF (RB/STB)
1.245
1.2375
1.23
1.2225
1.215
750
1500
2250
3000
3750
Pressure (psig)

Temperature 205 deg F
Bubble Point 1280 psig
Table 1 (T=205)

	Pressure	Gas Oil Ratio	Oil FVF	Oil Viscosity	Gas FVF
	psig	scf/STB	RB/STB	centipoise	ft3/scf
1	3215	315	1.217		
2	2250	315	1.229		
3	1280	315	1.243		
4					
5					
6					
7					
8					
9					

Match on: All / None

Match on	Std. Deviation	Parameter 1	Parameter 2
☑ Bubble Point	1.93268e-11	0.946542	-77.4974
☑ Gas Oil Ratio	8.2479e-10	0.909829	60.6955
☑ Oil FVF	1.72907e-7	1.0172	0.0206715
Above Bubble Point		0.177341	8.93167
☐ Oil Viscosity		1	0
☐ Gas FVF		1	0
☐ Gas Viscosity		1	0

Correlations
Pb,Rs,Bo: Lasater
Oil viscosity: Beal et al
☑ Match All

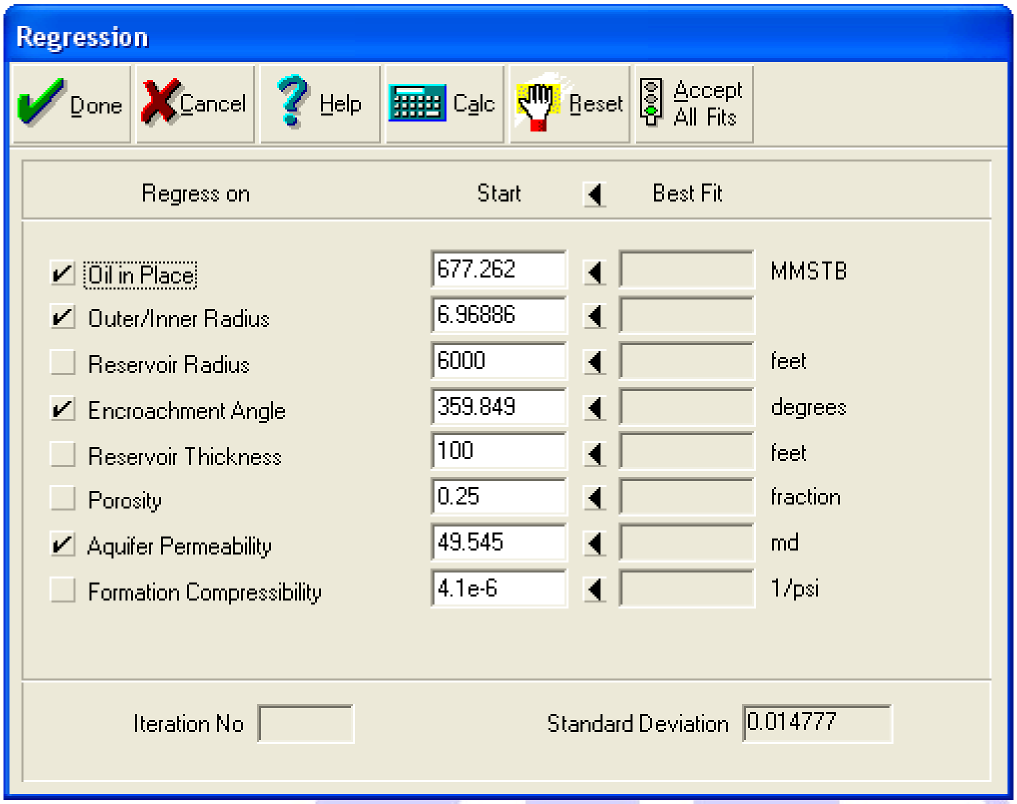
	Temperature (deg F)
1	205

Options Summary
Fluid: Oil
Method: Black Oil
Separator: Single-Stage

PVT Input Data
Form. GOR: 315.000 (scf/STB)
Oil Grav: 37.000 (API)
Gas Grav: 0.600 (sp. gravity)

.

With PVT re-matched, the history match regression was re-done to provide STOIIP approximately equal to 650MMstb. This further illustrates the sensitivity of the PVT model with regards to material balance modelling. With this done, the later history period is enabled and a closer match is obtained. The re-gression was then done with the entire production history enabled and STOIIP was calculated at 670MMstb. The simulation results also validate the history match already done.

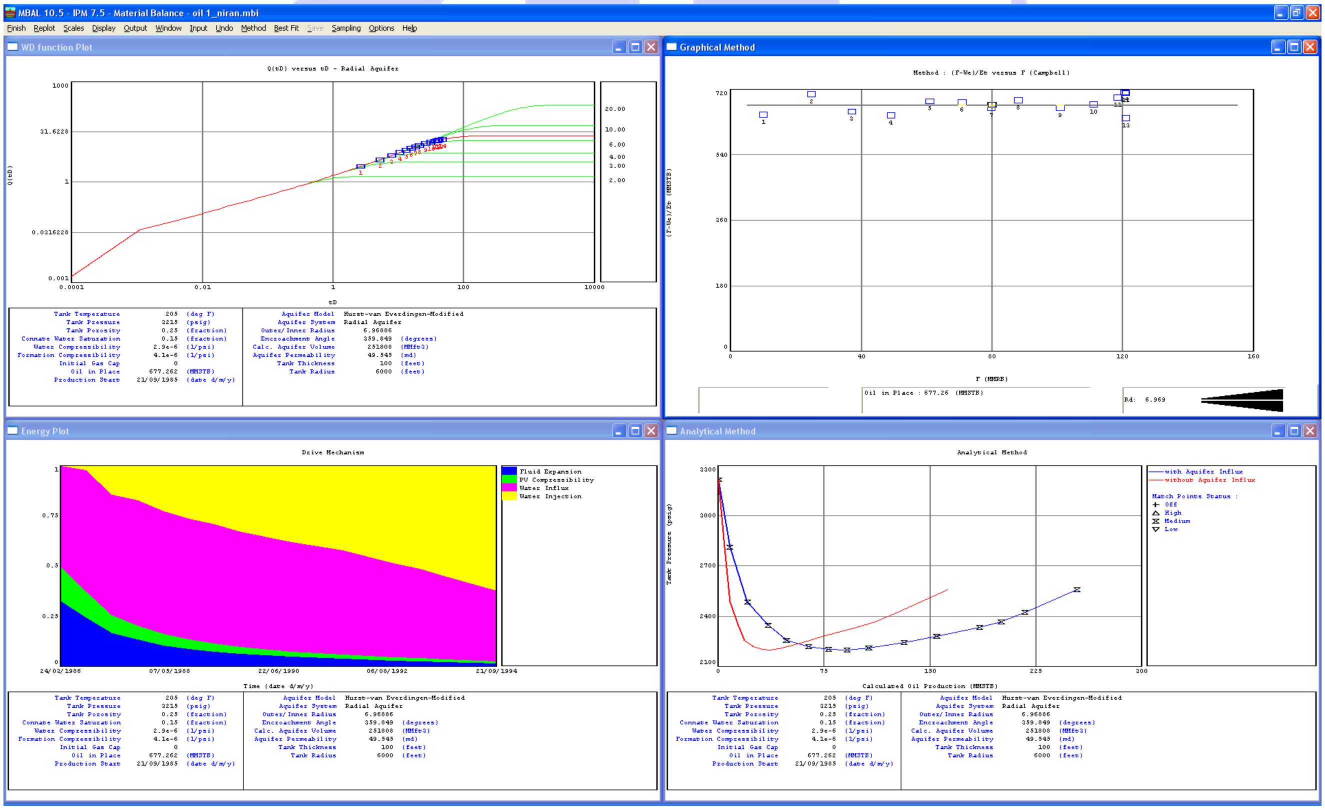


Regression
Done
Cancel
Help
Calc
Reset
Accept All Fits

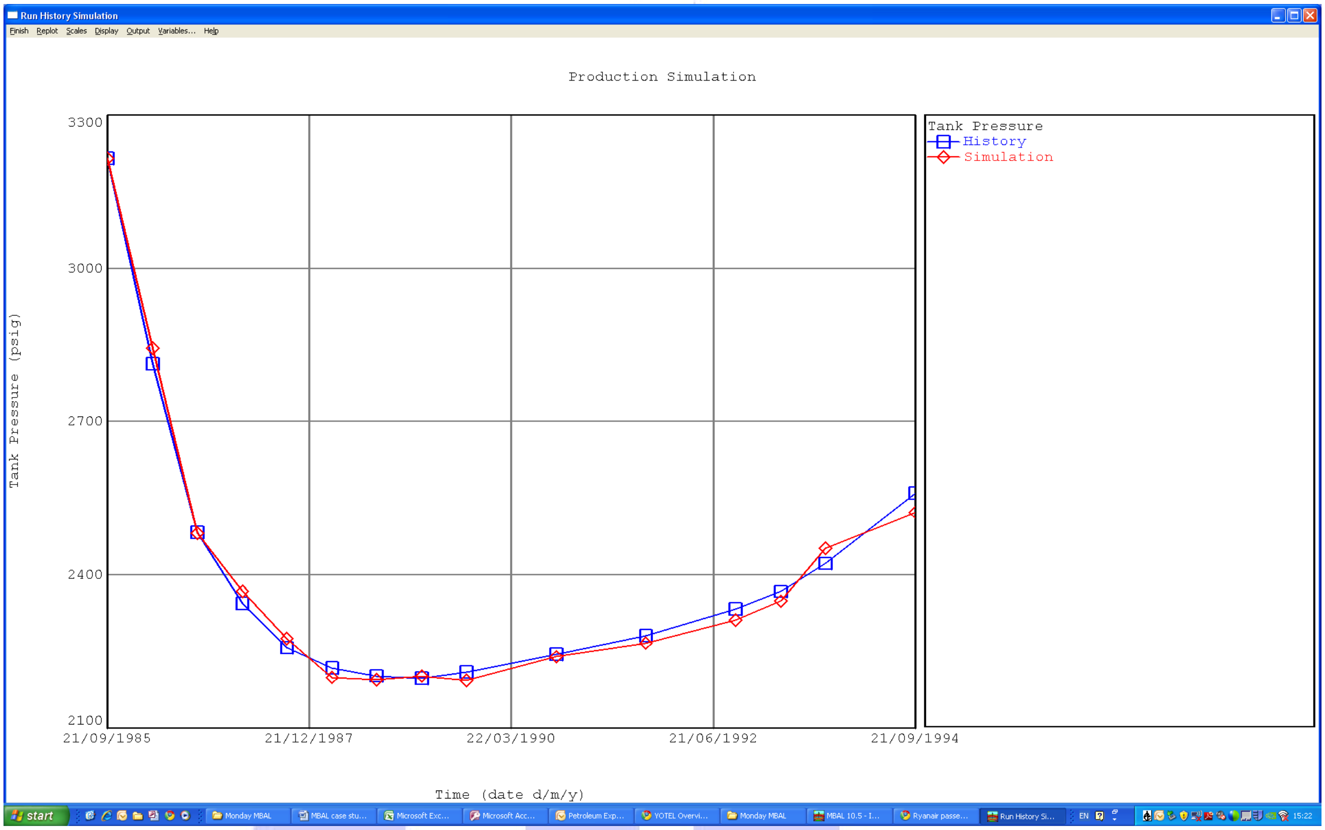
Regress on	Start	Best Fit	
☑ Oil in Place	677.262		MMSTB
☑ Outer/Inner Radius	6.96886		
☐ Reservoir Radius	6000		feet
☑ Encroachment Angle	359.849		degrees
☐ Reservoir Thickness	100		feet
☐ Porosity	0.25		fraction
☑ Aquifer Permeability	49.545		md
☐ Formation Compressibility	4.1e-6		1/psi

Iteration No

Standard Deviation 0.014777



MBAL 10.5 - IPM 7.5 - Material Balance - oil 1_niran.mbi
WD function Plot
Graphical Method
Energy Plot
Analytical Method
Q(tD) versus tD - Radial Aquifer
Drive Mechanism
Analytical Method


Run History Simulation
Finish Replot Scales Display Output Variables... Help
Production Simulation
Tank Pressure (psig)
3300
3000
2700
2400
2100
21/09/1985
21/12/1987
22/03/1990
21/06/1992
21/09/1994
Time (date d/m/y)
Tank Pressure
History
Simulation
start

The analysis above gives an overview of an approach to matching MBAL tank model. As discussed before, by starting from very simple assumptions of a tank model, the engineer can have greater modelling control and successfully guide the model to represent the actual reservoir behaviour.

4.2 Case study 2

This case study looks at a gas reservoir that has has some production.

The objective is to create a history matched reservoir model: previous attempts to date have failed and thus this exercise requires a review of the data specified combined with an understanding of the physics occurring.

4.2.1 Approach

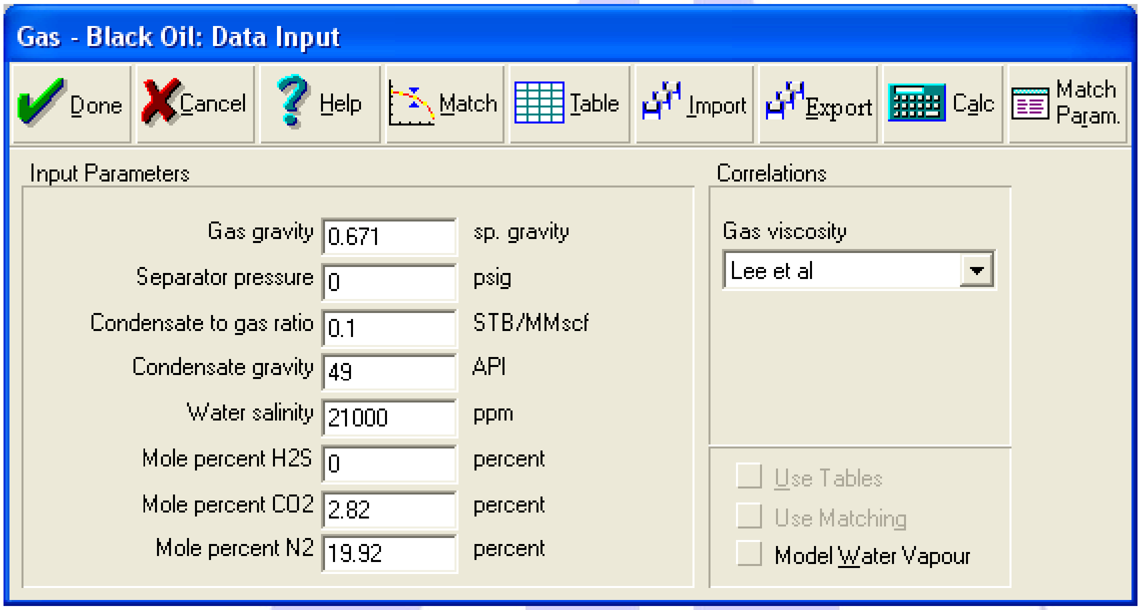
Similar to oil reservoir modelling, gas reservoirs can be modelled and history matched by analysing the Cole plot.

The Cole plot just like the Campbell plot for oils is a plot of (F – We)/ Et = G. Hence a plot of (F-

We)/G against F itself or time should be a straight line equal to the original gas in place G.

The model is started from single tank and the energies acting within the model can be analysed to justify further complexity or modification to the analysis.

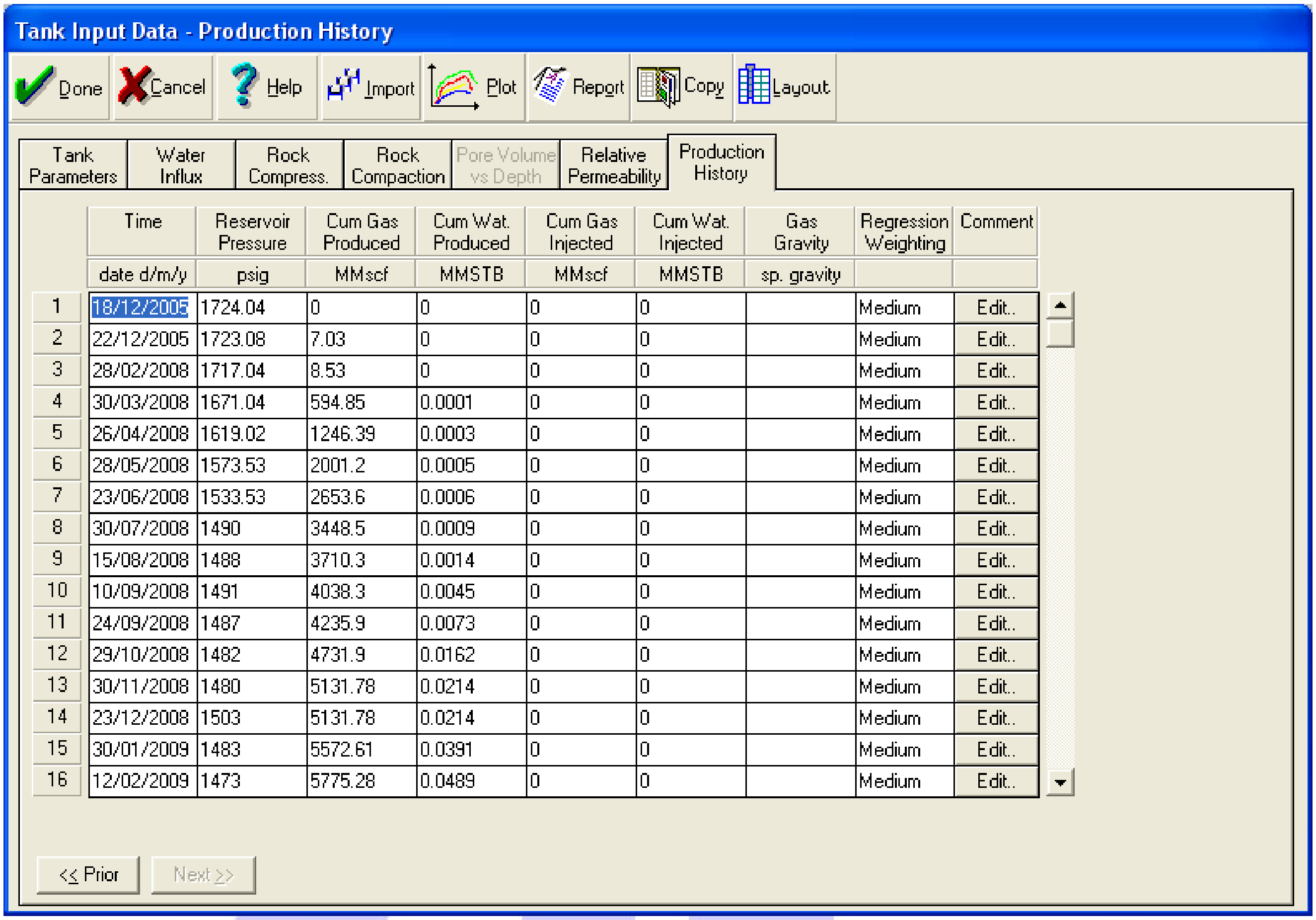
The PVT data for the gas is entered and the production history is shown below:


Gas - Black Oil: Data Input
Done
Cancel
Help
Match
Table
Import
Export
Calc
Match Param.
Input Parameters
Correlations

Gas gravity 0.671 sp. gravity
Separator pressure 0 psig
Condensate to gas ratio 0.1 STB/MMscf
Condensate gravity 49 API
Water salinity 21000 ppm
Mole percent H2S 0 percent
Mole percent CO2 2.82 percent
Mole percent N2 19.92 percent

Gas viscosity: Lee et al

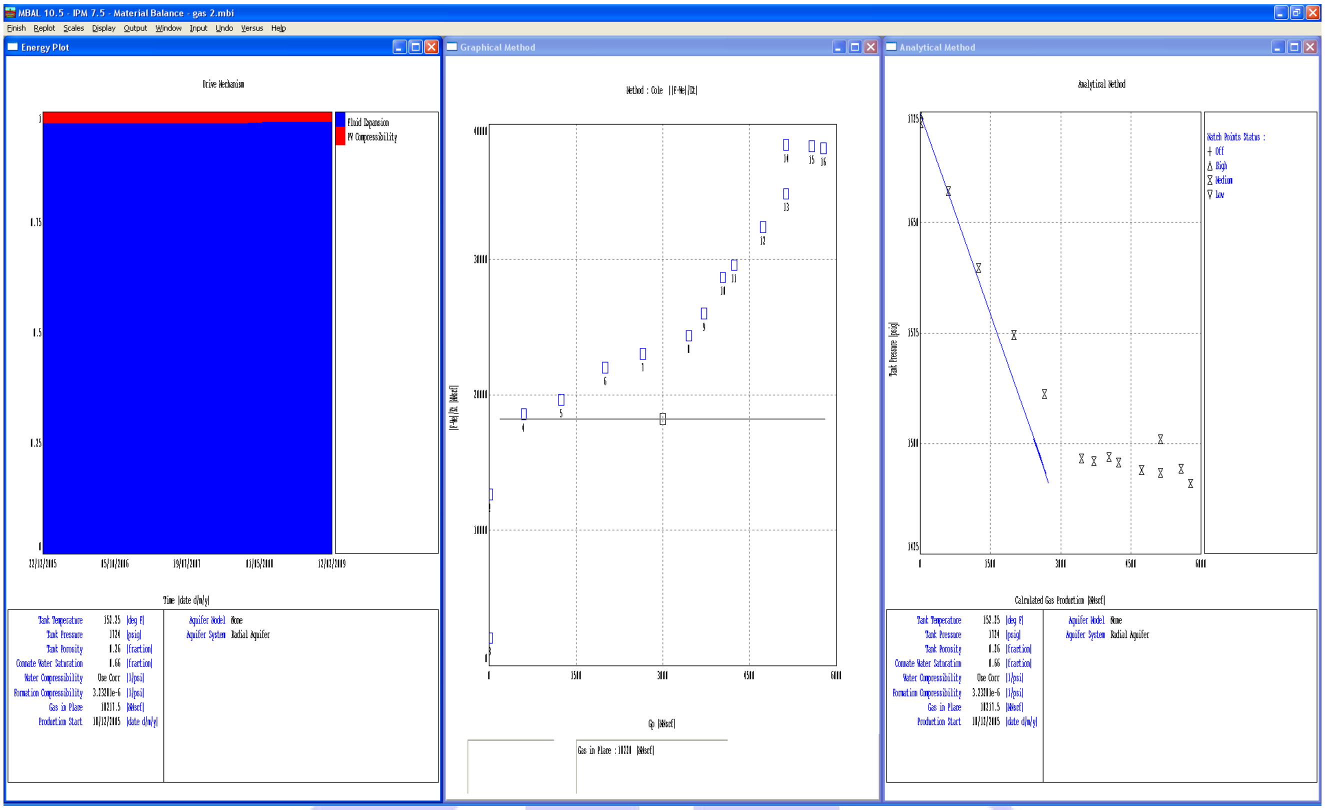
☐ Use Tables
☐ Use Matching
☐ Model Water Vapour


Tank Input Data - Production History
Done
Cancel
Help
Import
Plot
Report
Copy
Layout
Tank Parameters
Water Influx
Rock Compress.
Rock Compaction
Pore Volume vs Depth
Relative Permeability
Production History
<< Prior
Next >>

	Time	Reservoir Pressure	Cum Gas Produced	Cum Wat. Produced	Cum Gas Injected	Cum Wat. Injected	Gas Gravity	Regression Weighting	Comment
	date d/m/y	psig	MMscf	MMSTB	MMscf	MMSTB	sp. gravity		
1	18/12/2005	1724.04	0	0	0	0		Medium	Edit..
2	22/12/2005	1723.08	7.03	0	0	0		Medium	Edit..
3	28/02/2008	1717.04	8.53	0	0	0		Medium	Edit..
4	30/03/2008	1671.04	594.85	0.0001	0	0		Medium	Edit..
5	26/04/2008	1619.02	1246.39	0.0003	0	0		Medium	Edit..
6	28/05/2008	1573.53	2001.2	0.0005	0	0		Medium	Edit..
7	23/06/2008	1533.53	2653.6	0.0006	0	0		Medium	Edit..
8	30/07/2008	1490	3448.5	0.0009	0	0		Medium	Edit..
9	15/08/2008	1488	3710.3	0.0014	0	0		Medium	Edit..
10	10/09/2008	1491	4038.3	0.0045	0	0		Medium	Edit..
11	24/09/2008	1487	4235.9	0.0073	0	0		Medium	Edit..
12	29/10/2008	1482	4731.9	0.0162	0	0		Medium	Edit..
13	30/11/2008	1480	5131.78	0.0214	0	0		Medium	Edit..
14	23/12/2008	1503	5131.78	0.0214	0	0		Medium	Edit..
15	30/01/2009	1483	5572.61	0.0391	0	0		Medium	Edit..
16	12/02/2009	1473	5775.28	0.0489	0	0		Medium	Edit..

4.2.2 History Matching

The Cole plot clearly shows two gradients showing different energies acting at different points in time. This is also seen on the analytical plot. The first increasing upward gradient from day one is more likely due to the effect of aquifer acting. A more plausible explanation is due to the logarithmic shape of the gradient indicating some transient effect. The later gradient on the other hand shows the effect of another energy source including the acting aquifer. This second energy source could be the effect of a leaky fault in an adjoining compartment of the tank. This is also explained by the linear shape of the gradient. This means the reservoir is most likely compartmentalised and can be represented using a multiple tank unit.


MBAL 10.5 - IPM 7.5 - Material Balance - gas 2.mbi
Finish Replot Scales Display Output Window Input Undo Versus Help
Energy Plot
Drive Mechanism
Fluid Expansion
PV Compressibility
1
0.75
0.5
0.25
0
22/12/2005
15/10/2006
19/07/2007
01/05/2008
12/02/2009
Time (date d/m/y)
Graphical Method
Method : Cole ((F-We)/Et)
(F-We)/Et (MMscf)
40000
30000
20000
10000
0
1500
3000
4500
6000
Gp (MMscf)
Analytical Method
Tank Pressure (psig)
1725
1650
1575
1500
1425
Calculated Gas Production (MMscf)
Match Points Status :
Off
High
Medium
Low

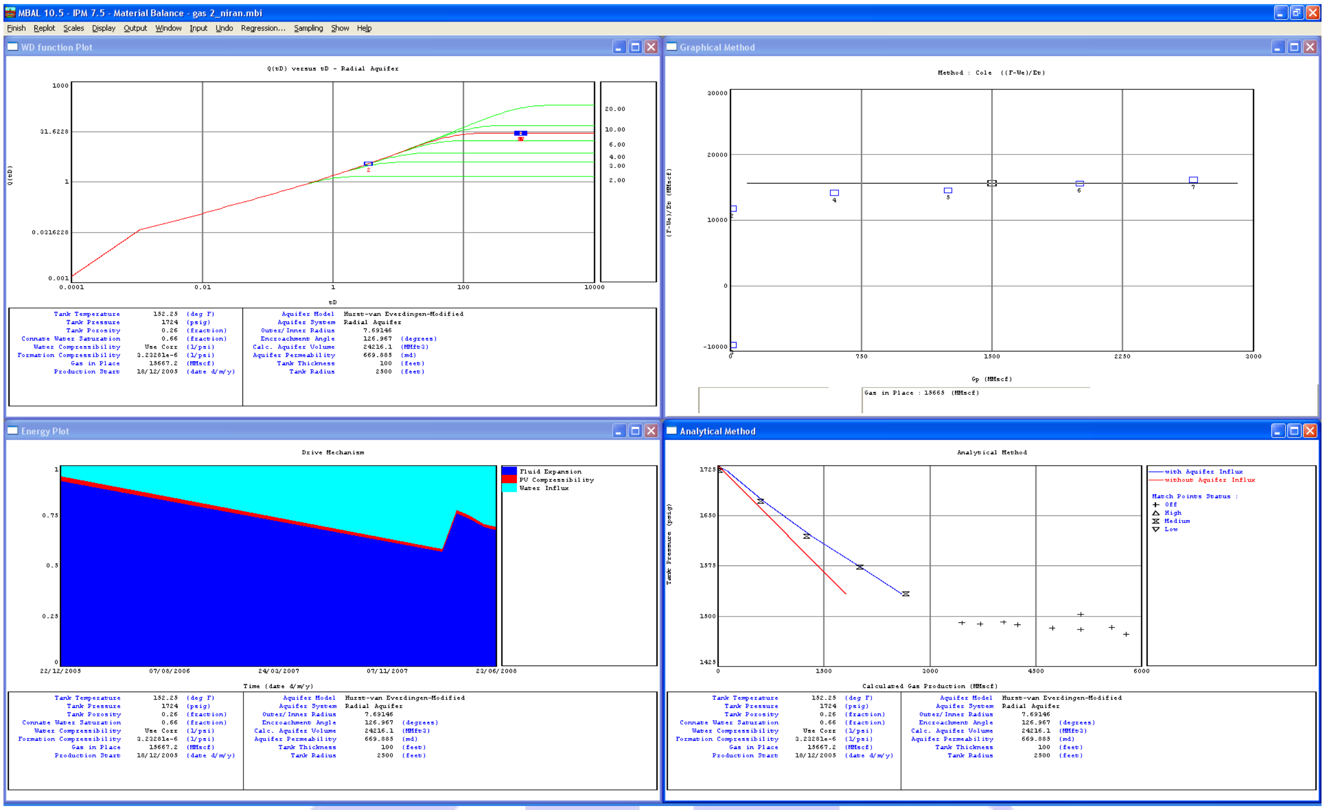
Tank Temperature	152.25	(deg F)
Tank Pressure	1724	(psig)
Tank Porosity	0.26	(fraction)
Connate Water Saturation	0.66	(fraction)
Water Compressibility	Use Corr	(1/psi)
Formation Compressibility	3.23201e-6	(1/psi)
Gas in Place	10211.5	(MMscf)
Production Start	01/12/2005	(date d/m/y)

Aquifer Model None
Aquifer System Radial Aquifer

Gas in Place : 10220 (MMscf)

However, the first section of the plot shall first be analysed to obtain the aquifer strength and original volumes of gas in place. Later on, a second tank shall be added and to analyse the second gradient with respect to the total system.

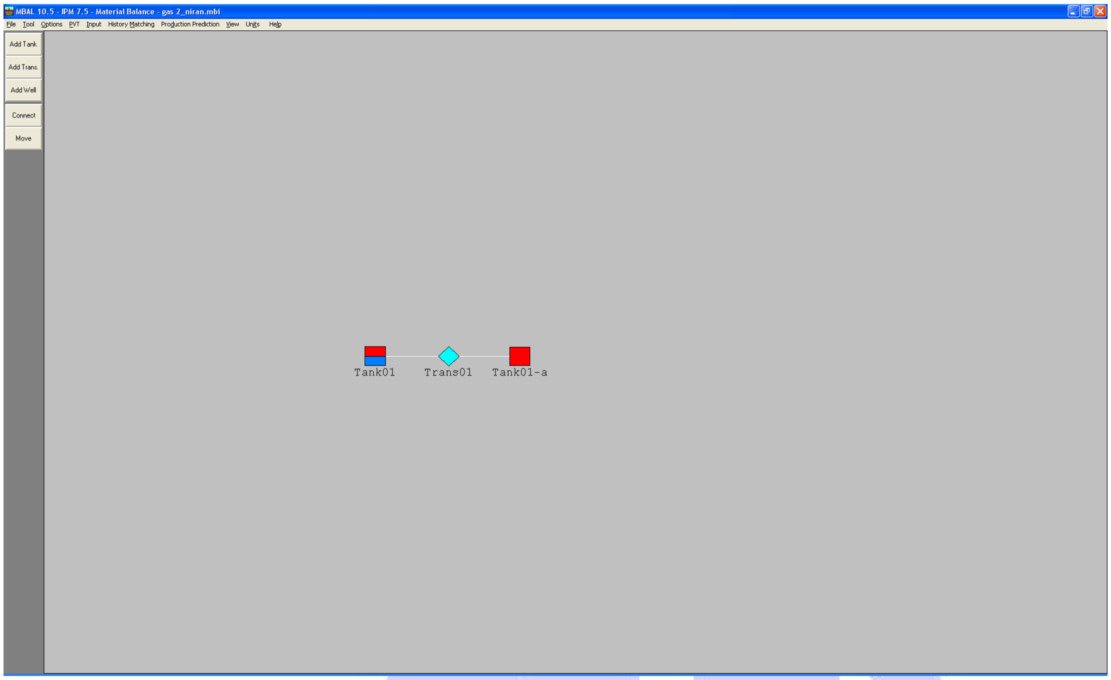
An aquifer model is added to the tank and the regression is performed on the analytical plot as shown below. This gives a GIIP approximately 15.5Bscf.

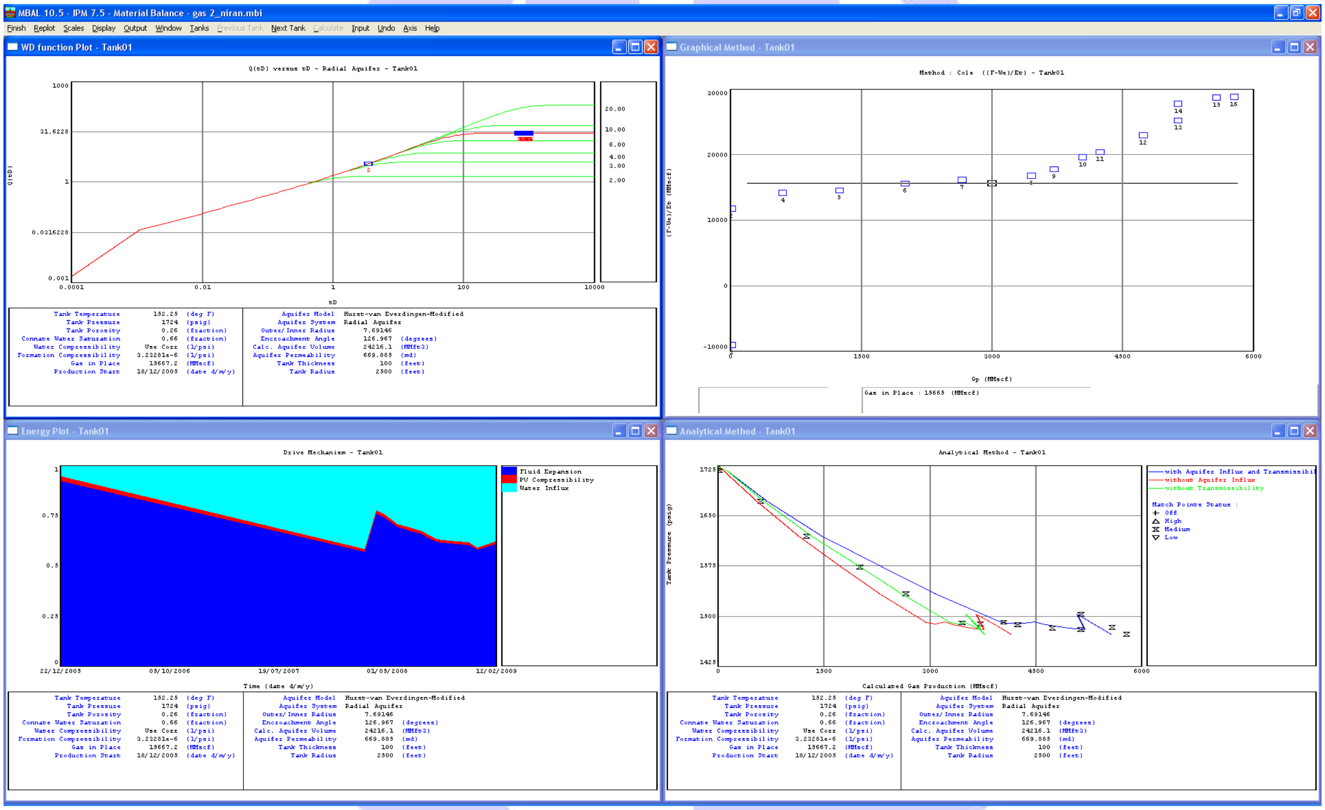

MBAL 10.5 - IPM 7.5 - Material Balance - gas 2_niran.mbi
Finish Replot Scales Display Output Window Input Undo Regression... Sampling Show Help
WD function Plot
Q(tD) versus tD - Radial Aquifer
Q(tD)
tD
Graphical Method
Method : Cole ((F-We)/Et)
(F-We)/Et (MMscf)
Gp (MMscf)
Energy Plot
Drive Mechanism
Fluid Expansion
PV Compressibility
Water Influx
Time (date d/m/y)
Analytical Method
Analytical Method
Tank Pressure (psig)
Calculated Gas Production (MMscf)
with Aquifer Influx
without Aquifer Influx
Match Points Status :
Off
High
Medium
Low

Tank Temperature	152.25	(deg F)	Aquifer Model	Hurst-van Everdingen-Modified	
Tank Pressure	1724	(psig)	Aquifer System	Radial Aquifer	
Tank Porosity	0.26	(fraction)	Outer/Inner Radius	7.69146	
Connate Water Saturation	0.66	(fraction)	Encroachment Angle	126.967	(degrees)
Water Compressibility	Use Corr	(1/psi)	Calc. Aquifer Volume	24216.1	(MMft3)
Formation Compressibility	3.23281e-6	(1/psi)	Aquifer Permeability	669.885	(md)
Gas in Place	15667.2	(MMscf)	Tank Thickness	100	(feet)
Production Start	18/12/2005	(date d/m/y)	Tank Radius	2500	(feet)

Gas in Place : 15665 (MMscf)

The second gradient is then enabled and a second tank (similar to the first) is inserted in the model. This second tank has no aquifer and no production data while other properties are the same as the first tank. Both tanks are then connected together and the history match reviewed. The analytical plot is shown below.


MBAL 10.5 - IPM 7.5 - Material Balance - gas 2_niran.mbi
File Tool Options PVT Input History Matching Production Prediction View Units Help
Add Tank
Add Trans.
Add Well
Connect
Move
Tank01
Trans01
Tank01-a


MBAL 10.5 - IPM 7.5 - Material Balance - gas 2_niran.mbi
Finish Replot Scales Display Output Window Tanks Previous Tank Next Tank Calculate Input Undo Axis Help
WD function Plot - Tank01
Q(tD) versus tD - Radial Aquifer - Tank01
Q(tD)
tD
Graphical Method - Tank01
Method : Cole ((F-We)/Et) - Tank01
(F-We)/Et (MMscf)
Gp (MMscf)
Energy Plot - Tank01
Drive Mechanism - Tank01
Fluid Expansion
PV Compressibility
Water Influx
Time (date d/m/y)
Analytical Method - Tank01
Analytical Method - Tank01
Tank Pressure (psig)
Calculated Gas Production (MMscf)
with Aquifer Influx and Transmissibil
without Aquifer Influx
without Transmissibility
Match Points Status :
Off
High
Medium
Low

WD function Plot - Tank01

Tank Temperature	152.25	(deg F)	Aquifer Model	Hurst-van Everdingen-Modified	
Tank Pressure	1724	(psig)	Aquifer System	Radial Aquifer	
Tank Porosity	0.26	(fraction)	Outer/Inner Radius	7.69146	
Connate Water Saturation	0.66	(fraction)	Encroachment Angle	126.967	(degrees)
Water Compressibility	Use Corr	(1/psi)	Calc. Aquifer Volume	24216.1	(MMft3)
Formation Compressibility	3.23281e-6	(1/psi)	Aquifer Permeability	669.885	(md)
Gas in Place	15667.2	(MMscf)	Tank Thickness	100	(feet)
Production Start	18/12/2005	(date d/m/y)	Tank Radius	2500	(feet)

Graphical Method - Tank01

Gas in Place : 15665 (MMscf)

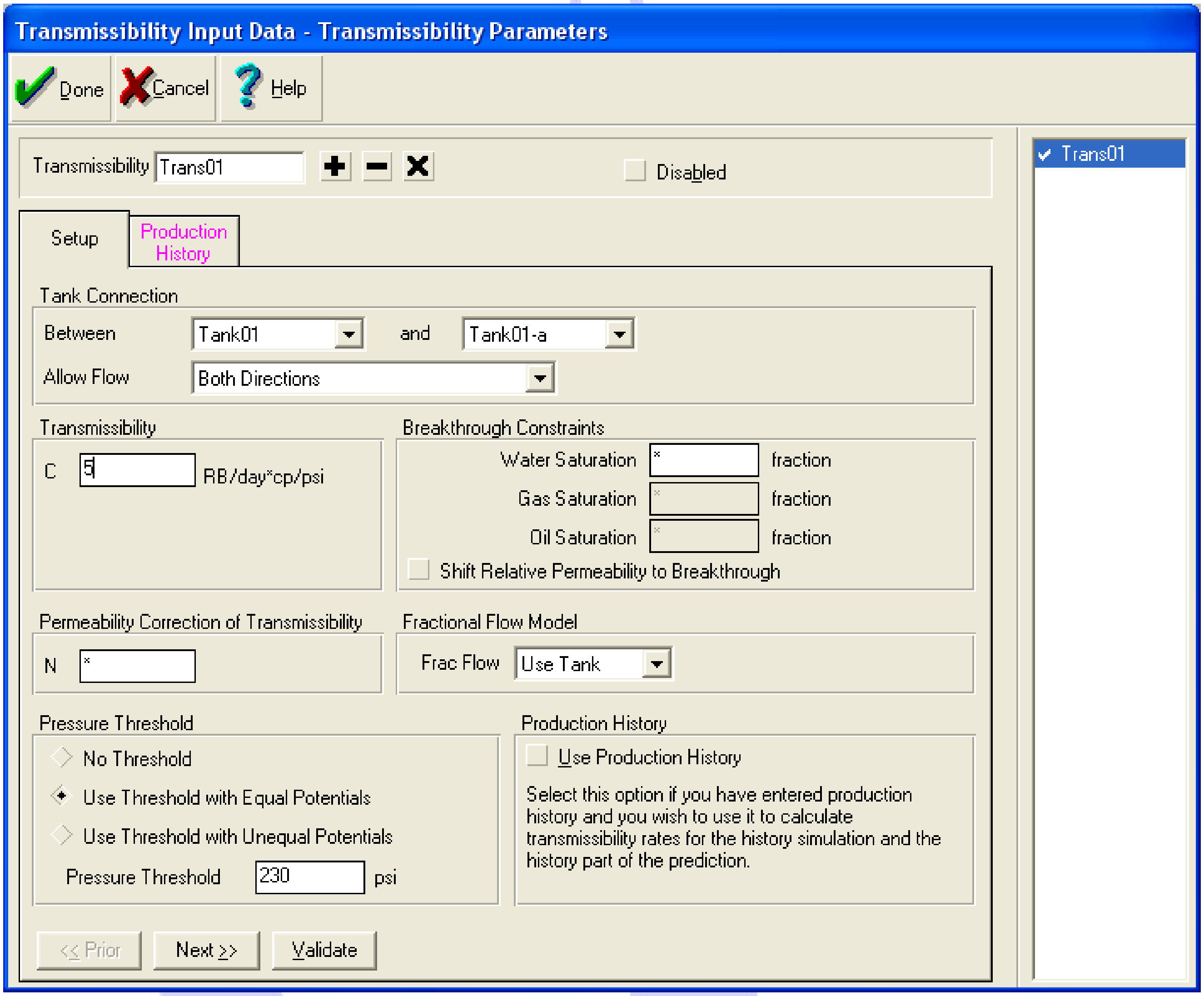
Energy Plot - Tank01

Tank Temperature	152.25	(deg F)	Aquifer Model	Hurst-van Everdingen-Modified	
Tank Pressure	1724	(psig)	Aquifer System	Radial Aquifer	
Tank Porosity	0.26	(fraction)	Outer/Inner Radius	7.69146	
Connate Water Saturation	0.66	(fraction)	Encroachment Angle	126.967	(degrees)
Water Compressibility	Use Corr	(1/psi)	Calc. Aquifer Volume	24216.1	(MMft3)
Formation Compressibility	3.23281e-6	(1/psi)	Aquifer Permeability	669.885	(md)
Gas in Place	15667.2	(MMscf)	Tank Thickness	100	(feet)
Production Start	18/12/2005	(date d/m/y)	Tank Radius	2500	(feet)

Analytical Method - Tank01

Tank Temperature	152.25	(deg F)	Aquifer Model	Hurst-van Everdingen-Modified	
Tank Pressure	1724	(psig)	Aquifer System	Radial Aquifer	
Tank Porosity	0.26	(fraction)	Outer/Inner Radius	7.69146	
Connate Water Saturation	0.66	(fraction)	Encroachment Angle	126.967	(degrees)
Water Compressibility	Use Corr	(1/psi)	Calc. Aquifer Volume	24216.1	(MMft3)
Formation Compressibility	3.23281e-6	(1/psi)	Aquifer Permeability	669.885	(md)
Gas in Place	15667.2	(MMscf)	Tank Thickness	100	(feet)
Production Start	18/12/2005	(date d/m/y)	Tank Radius	2500	(feet)

The analytical plot now shows over-estimation of the gas produced compared to the history data points. In particular, the match that was obtained for the first tank has been lost because the second tank is recharging the first tank from start. The objective is now to create a pressure threshold for the connection between the tanks such that before this the first tank is acting and after which both tanks are acting. This happens after about 230psi depletion.



Transmissibility Input Data - Transmissibility Parameters

Transmissibility: Trans01

☐ Disabled

Tank Connection

Between: Tank01 and Tank01-a

Allow Flow: Both Directions

Transmissibility

C: 5 RB/day*cp/psi

Breakthrough Constraints

Water Saturation: * fraction

Gas Saturation: * fraction

Oil Saturation: * fraction

☐ Shift Relative Permeability to Breakthrough

Permeability Correction of Transmissibility

N: *

Fractional Flow Model

Frac Flow: Use Tank

Pressure Threshold

○ No Threshold

● Use Threshold with Equal Potentials

○ Use Threshold with Unequal Potentials

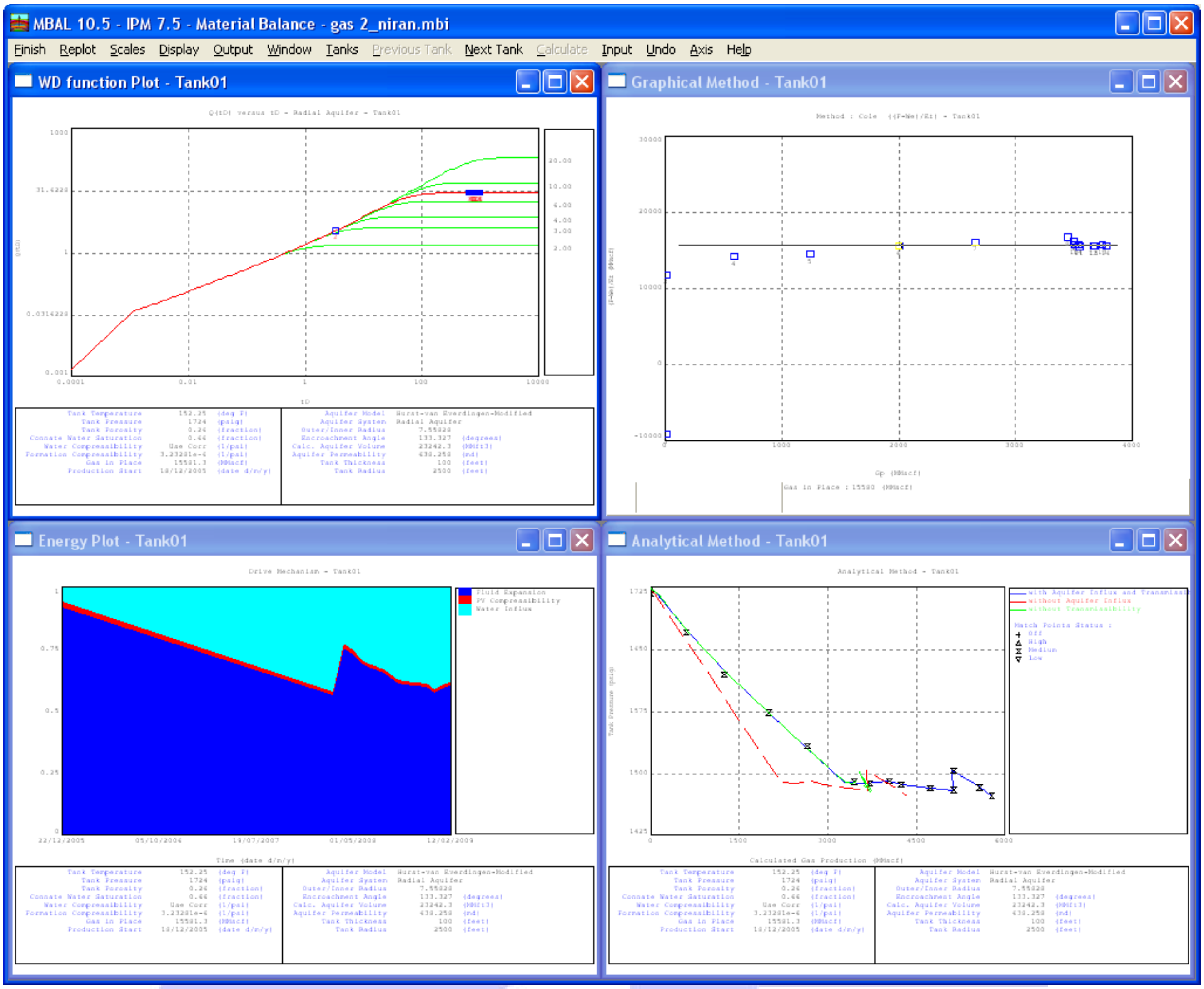
Pressure Threshold: 230 psi

Production History

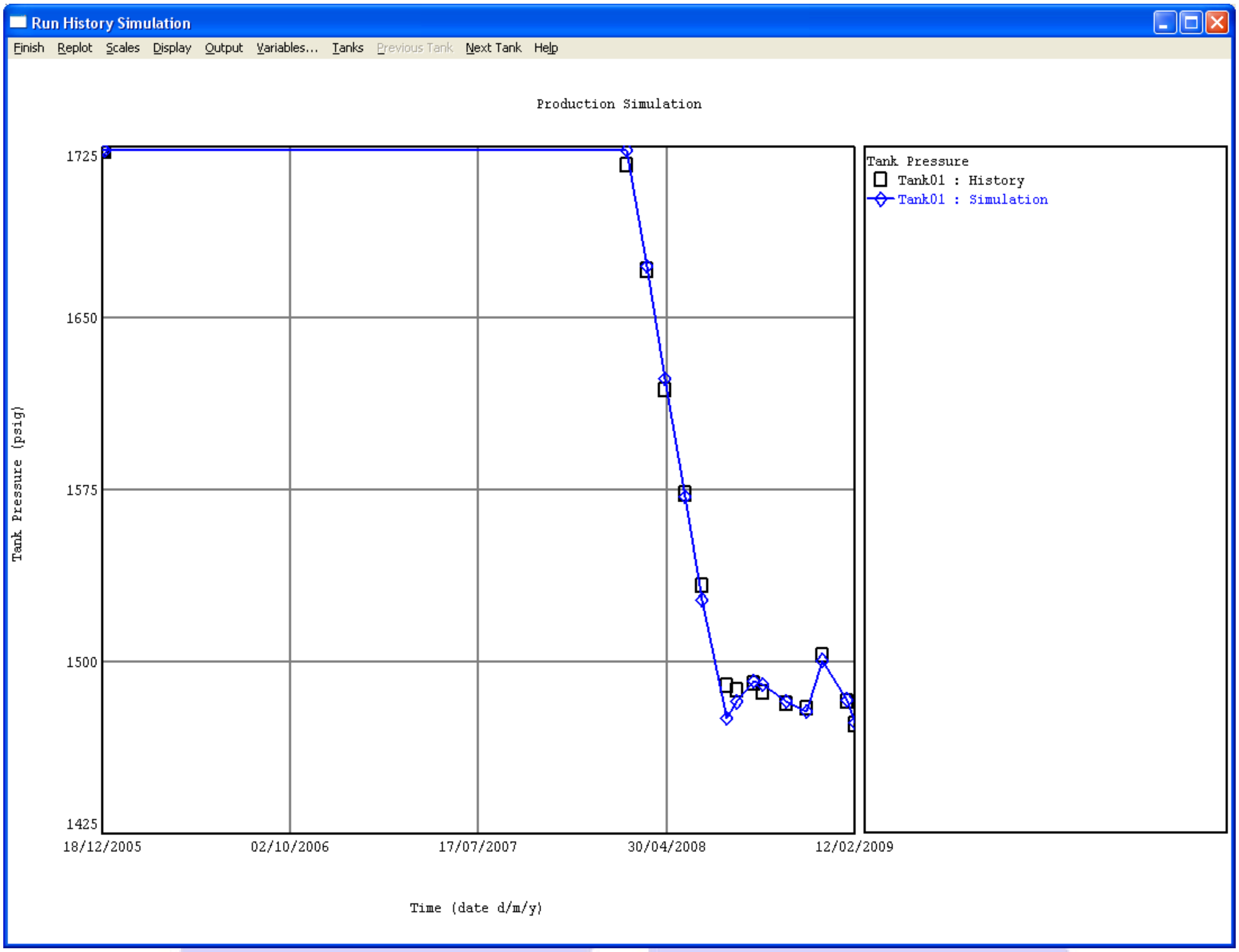
☐ Use Production History

Select this option if you have entered production history and you wish to use it to calculate transmissibility rates for the history simulation and the history part of the prediction.

With this in place, the match for the first tank is re-instated and the regression for the multiple tanks can then proceed


MBAL 10.5 - IPM 7.5 - Material Balance - gas 2_niran.mbi
Finish
Replot
Scales
Display
Output
Window
Tanks
Previous Tank
Next Tank
Calculate
Input
Undo
Axis
Help
WD function Plot - Tank01
Q(tD) versus tD - Radial Aquifer - Tank01
1000
31.6228
1
0.0316228
0.001
0.0001
0.01
1
100
10000
tD
20.00
10.00
6.00
4.00
3.00
2.00
Graphical Method - Tank01
Method : Cole ((F-We)/Et) - Tank01
30000
20000
10000
0
-10000
0
1000
2000
3000
4000
Gp (MMscf)
Gas in Place : 15580 (MMscf)
Energy Plot - Tank01
Drive Mechanism - Tank01
1
0.75
0.5
0.25
0
22/12/2005
05/10/2006
19/07/2007
01/05/2008
12/02/2009
Time (date d/m/y)
Fluid Expansion
PV Compressibility
Water Influx
Analytical Method - Tank01
Analytical Method - Tank01
1725
1650
1575
1500
1425
0
1500
3000
4500
6000
Tank Pressure (psig)
Calculated Gas Production (MMscf)
with Aquifer Influx and Transmissib
without Aquifer Influx
without Transmissibility
Match Points Status :
Off
High
Medium
Low

Tank Temperature	152.25	(deg F)	Aquifer Model	Hurst-van Everdingen-Modified	
Tank Pressure	1724	(psig)	Aquifer System	Radial Aquifer	
Tank Porosity	0.26	(fraction)	Outer/Inner Radius	7.55828	
Connate Water Saturation	0.46	(fraction)	Encroachment Angle	133.327	(degrees)
Water Compressibility	Use Corr	(1/psi)	Calc. Aquifer Volume	23242.3	(MMft3)
Formation Compressibility	3.23281e-6	(1/psi)	Aquifer Permeability	438.258	(md)
Gas in Place	15581.3	(MMscf)	Tank Thickness	100	(feet)
Production Start	18/12/2005	(date d/m/y)	Tank Radius	2500	(feet)


Run History Simulation
Finish Replot Scales Display Output Variables... Tanks Previous Tank Next Tank Help
Production Simulation
Tank Pressure (psig)
1725
1650
1575
1500
1425
18/12/2005
02/10/2006
17/07/2007
30/04/2008
12/02/2009
Time (date d/m/y)
Tank Pressure
Tank01 : History
Tank01 : Simulation

4.3 Case Study 3

The objective of this case study is to model a gas reservoir and review the current Gas initially in place (GIIP) that was estimated.

4.3.1 Approach

The traditional approach to gas reservoir modelling is to use the P/Z plot. This is a very simple and analytical tool for dry gas reservoirs with which reservoir engineers can easily deduce the original Gas in place. It is also convenient for use as government recognise its use.The material balance equation for a dry gas reservoir is:

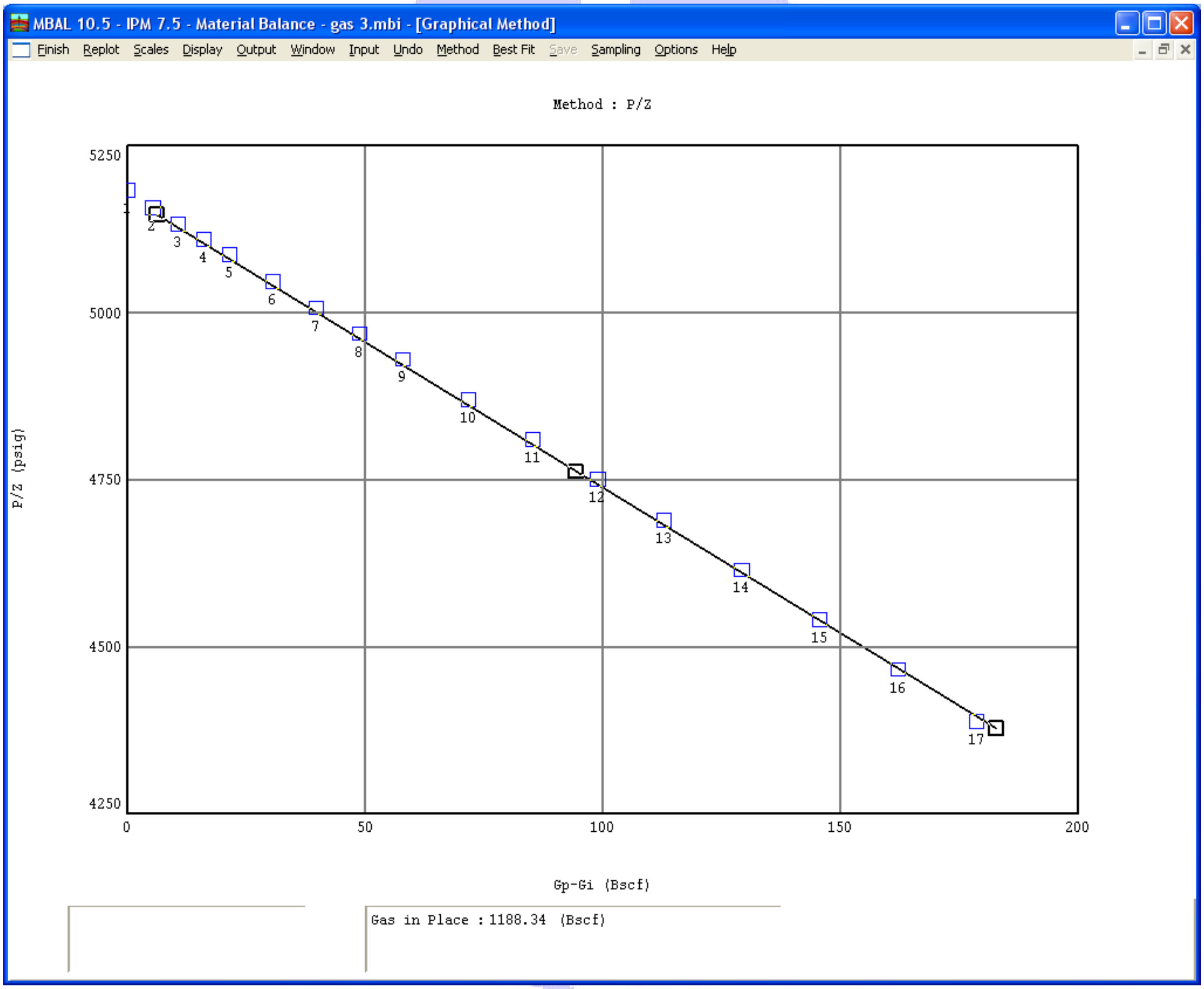
$$Gp = Gi \{1-(ZiP/PiZ)\}$$

For this particular study, the cummulative gas produced was a lot lower than the values obtained for the P/Z analysis and the objective was to investigate why. The approach taken is to analyse the P/Z plot with another graphical method: Cole plot.

A very important thing to note about the P/Z plot is that it does not take into account any other energy which may be acting on the system because it assumes only gas expansion within the reservoir. Hence any other source of energy e.g. aquifer influx is assumed to be due to gas and the P/Z plot may overestimate the fluid volumes in place. It normally takes large aquifer influx over a period of time to change the P/Z plot from which the engineer may deduce any acting drive mechanism.

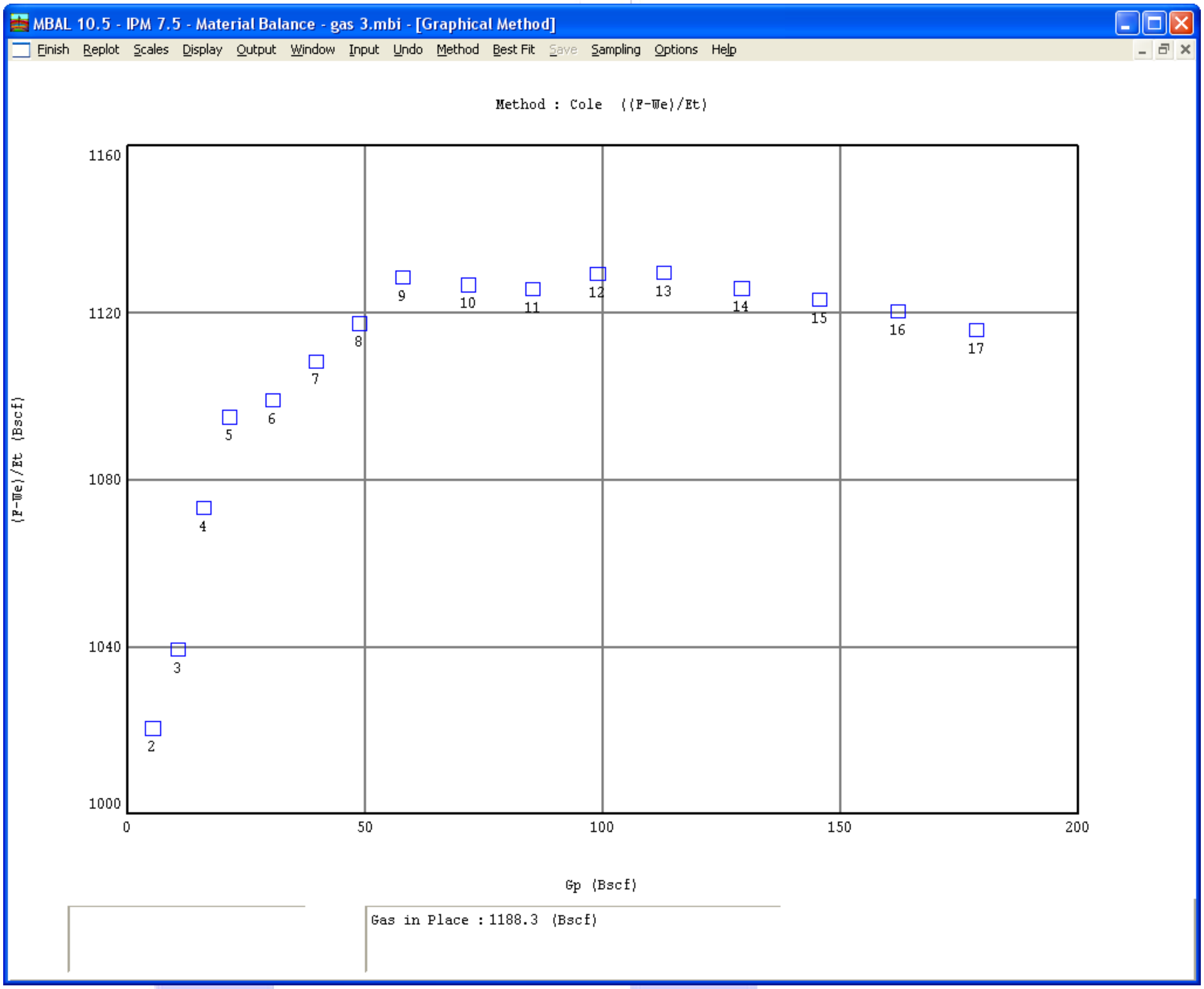
However an analysis with the Cole plot shows the effects of the drive mechanism clearly and in particular effect of an aquifer.

P/Z, GIIP = 1190 Bscf.


MBAL 10.5 - IPM 7.5 - Material Balance - gas 3.mbi - [Graphical Method]
Finish
Replot
Scales
Display
Output
Window
Input
Undo
Method
Best Fit
Save
Sampling
Options
Help
Method : P/Z
P/Z (psig)
5250
5000
4750
4500
4250
Gp-Gi (Bscf)
0
50
100
150
200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

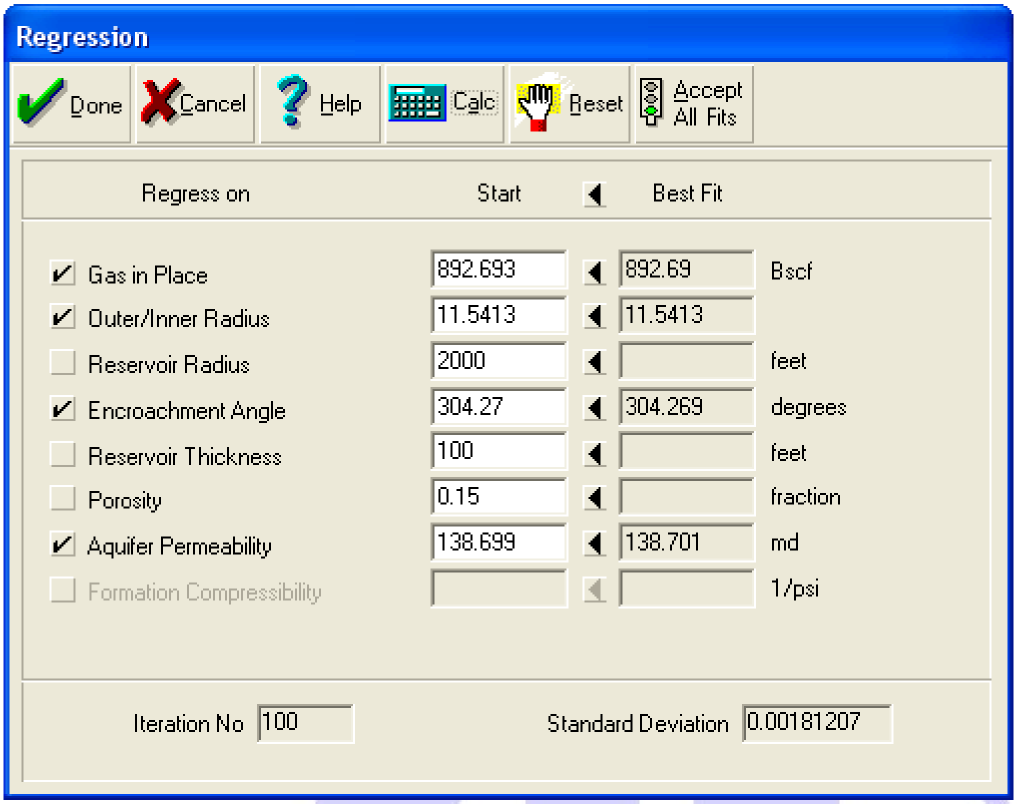
Gas in Place : 1188.34 (Bscf)

Cole plot for same conditions showing aquifer effect, GIIP = 1190Bscf


MBAL 10.5 - IPM 7.5 - Material Balance - gas 3.mbi - [Graphical Method]
Finish Replot Scales Display Output Window Input Undo Method Best Fit Save Sampling Options Help
Method : Cole ((F-We)/Et)
(F-We)/Et (Bscf)
1160
1120
1080
1040
1000
0
50
100
150
200
Gp (Bscf)
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

Gas in Place : 1188.3 (Bscf)

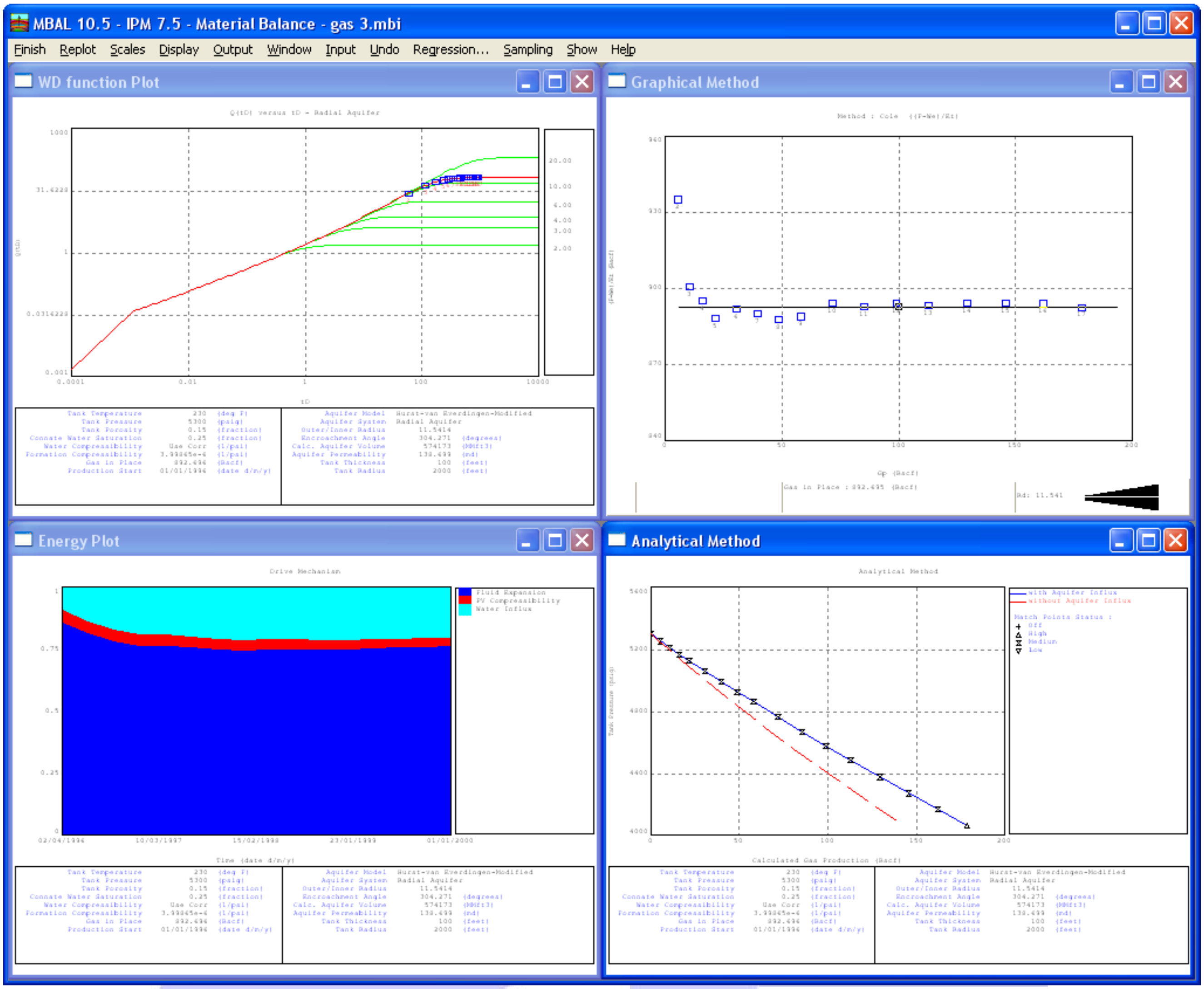
Performing the history match with an aquifer model, GIIP = 900Bscf.


Regression
Done
Cancel
Help
Calc
Reset
Accept All Fits

Regress on	Start	Best Fit	
☑ Gas in Place	892.693	892.69	Bscf
☑ Outer/Inner Radius	11.5413	11.5413	
☐ Reservoir Radius	2000		feet
☑ Encroachment Angle	304.27	304.269	degrees
☐ Reservoir Thickness	100		feet
☐ Porosity	0.15		fraction
☑ Aquifer Permeability	138.699	138.701	md
☐ Formation Compressibility			1/psi

Iteration No 100

Standard Deviation 0.00181207


MBAL 10.5 - IPM 7.5 - Material Balance - gas 3.mbi
Finish Replot Scales Display Output Window Input Undo Regression... Sampling Show Help
WD function Plot
Q(tD) versus tD - Radial Aquifer
1000
31.6228
1
0.0316228
0.001
0.0001
0.01
1
100
10000
tD
20.00
10.00
6.00
4.00
3.00
2.00
Graphical Method
Method : Cole ((F-We)/Et)
960
930
900
870
840
0
50
100
150
200
Gp (Bscf)
Gas in Place : 892.695 (Bscf)
Rd: 11.541
Energy Plot
Drive Mechanism
Fluid Expansion
PV Compressibility
Water Influx
Time (date d/m/y)
Analytical Method
Analytical Method
with Aquifer Influx
without Aquifer Influx
Match Points Status :
Off
High
Medium
Low
Tank Pressure (psig)
Calculated Gas Production (Bscf)

Tank Temperature	230	(deg F)	Aquifer Model	Hurst-van Everdingen-Modified	
Tank Pressure	5300	(psig)	Aquifer System	Radial Aquifer	
Tank Porosity	0.15	(fraction)	Outer/Inner Radius	11.5414	
Connate Water Saturation	0.25	(fraction)	Encroachment Angle	304.271	(degrees)
Water Compressibility	Use Corr	(1/psi)	Calc. Aquifer Volume	574173	(MMft3)
Formation Compressibility	3.99865e-6	(1/psi)	Aquifer Permeability	138.699	(md)
Gas in Place	892.696	(Bscf)	Tank Thickness	100	(feet)
Production Start	01/01/1996	(date d/m/y)	Tank Radius	2000	(feet)

Generally, in terms of GIIP estimates, using the P/Z plot may sometimes overestimate the GIIP by up to 30% when other drive mechanisms are acting which have not been accounted for. This is just in terms of reserves. This does not account for other scenarios which may affect production e.g. high water production leading to well loading e.t.c; these may cause the P/Z to overestimate GIIP by over 50%.

In general, it is recommend to always review the Cole plot for gas reservoirs to have a better picture on acting drive mechanisms in the system and better estimates of the fluid volumes in place.